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HISTORY: PROJECT FIRST, F-1 COMBUSTION STABILITY PROGRAM
VOLUME 2, BOOK 4

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FOREWORD

This is Volume 2, Book 4 of the History: Project First, F-1 Combustion Stability Program Report, prepared in compliance with the provisions of contract NASw-16, Mod 36 and Mod 44, Attachment B, the Rocketdyne F-1 Engine Development Program for the National Aeronautics and Space Administration.

ABSTRACT

A history of the F-1 Combustion Stability Program from July through September 1964 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described.

(Unclassified Abstract)

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INTRODUCTION

This report is a continuation of the history in which the theoretical investigations of the F-1 Combustion Stability Committee and the evaluations of injector concepts have been presented. Volume 2, Book 4 presents the history for the period from July through September 1964. During this period, the flight rating test (FRT) injector was evolved, and its development is discussed herein. Emphasis was placed upon the elimination of self-triggered instabilities and 400- and 500-cps buzz instabilities. Additional concepts which were evaluated were: the rotated fan, the reversed 5U injector, injectors with wall gap, and the Block 1 injector with canted oxidizer doublets adjacent to the radial baffles.

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SUMMARY

Primary emphasis during this report period was placed upon the development of the FRT injector. Both the stability and performance were improved without a loss in compatability. The concept of canting the LOX fans away from the radial baffles, employed with the FRT design, was found to be beneficial to dynamic stability with other multicompartment baffled injectors.

Work continued in the Hydrodynamics Unit to predict the flow distribution of F-1 injectors, and a digital model, which gave results in close agreement with the emperical results, was constructed.

Analytical studies were conducted to explain the 400- and 500-cps buzz instabilities. All test data were reviewed, the fan characteristics were studied, and the propellant manifold resonant frequencies were emperically determined.

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THEORY AND ANALYTICAL STUDIES

Few theories were advanced during this period because the major effort was in the development of the FRT injector. This injector used the proved concepts of low fuel injection velocity for improved stability and low oxidizer injection velocity for improved performance. It also helped to establish the concept of canting the LOX fans away from the radial baffles. Additional investigations were made with injectors with wall gap and reversed 5U orifice patterns. These concepts have been discussed in previous books and are only briefly discussed herein.

Analytical studies were conducted to determine the cause of excessive heating and erosion of the nozzle-to-nozzle-extension transition region, to predict the propellant distribution of ring-type injectors, and to determine the cause of the 400- and 500-cps buzz instabilities. The results of these studies are presented in the following paragraphs.

CANTED FAN THEORY

The concept of minimizing the propellants on the radial baffle surfaces, achieved by drilling the orifice adjacent to the radial baffle at an angle greater than the angle of its impinging orifice, was shown to have a pronounced effect on dynamic stability. It was very effective with thirteen compartment baffled injectors, but did not prove successful with tribaffled injectors. The theory is that the confining surfaces of the baffles are a mechanism for resurge because waves are able to coalesce in a corner to form a single, high-amplitude wave. The degree of reaction is minimized by canting the LOX away from the baffles so that a wave cannot be sustained in this area, i.e., the wave will not be sustained without energy addition.

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REVERSED 5U PATTERN

The reversed 5U orifice pattern is, as the name indicates, a reverse of the F-1 5U orifice pattern. In the 5U, the LOX orifices are matched to the outboard fuel orifices; in the reversed 5U, the outboard LOX orifices matched to the adjacent inboard fuel orifices (Fig. 1). The outer fuel ring on the reversed 5U showerhead orifices directed toward the chamber wall, such that essentially all the fuel injected is used as wall coolant. The outer periphery is then basically oxidizer rich.

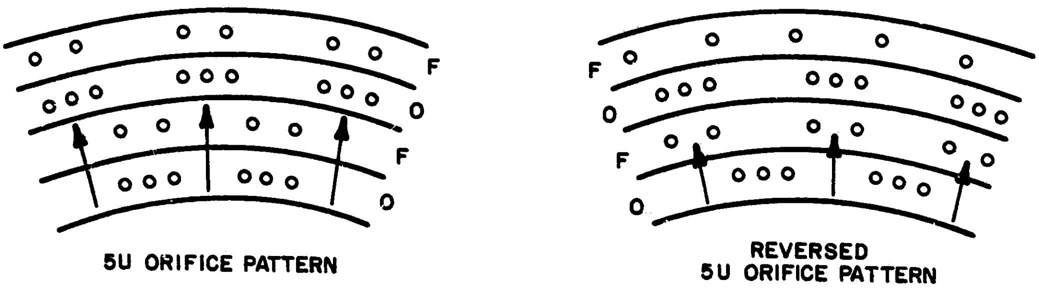

Figure 1. 5U and Reversed 5U Orifice Patterns

The basic theory behind this injector is that, since LOX vaporizes much more rapidly than fuel, it is more easily displaced by winds across the injector face. The displaced LOX reacts with the fuel fans and sustains the wave as it traverses the injector. It is true that LOX is displaced into the fuel fans by a wave travelling toward the center of the chamber, but it is believed that this is a less sensitive zone, and that the wave amplification will be reduced.

This belief that the outer zone is the most sensitive region in suppressing combustion instability has led to the concept of wall gap, and the use of oxidizer in the outer periphery. The absence of propellants and subsequent decrease in reaction will allow the sustaining wave to diminish.

Wall gap has proved very successful when used in conjunction with the large-fuel-orifice, baffled injector U/N 090 (type 5839Y), but the performance has been very low. To improve performance, a small-fuel-orifice injector was designed. When tested, the stability was unchanged. The concept was also used on a flat-face injector and did not prove successful.

The oxidizer-rich zone in the outer periphery imposed a compatability problem. In one test on injector U/N X017, several holes were burned through the combustion chamber wall.

NOZZLE EXTENSION

The elimination of film coolant on certain injectors produced excessive heating and erosion of the F-1 nozzle extension. An experimental program was initiated by the F-1 Combustion Stability Group to determine the aerodynamic losses and detrimental flow losses in this area. The tests were conducted at the N.A.A. Los Angeles Division, Thermodynamics Laboratory.

A two-dimensional model, which simulated that portion of the nozzle at which the nozzle extension is connected to the tubular wall nozzle (Fig. 2) was constructed. Gas flow past this nozzle section was approximated by testing the model on a free-surface, open-channel water table (Fig. 3). Still photographs of the wave patterns and motion pictures of dye injection and floating particles showing the streamlines, were taken. Flow patterns were studied for eight different hardware configurations. These were the several combinations of flow, both with and without secondary turbine exhaust injection, with and without ground support tabs that protrude into the flow field, and with the position of the first transition shingle altered. Photographs of these types of flow are shown in Fig. 4 through 10. Conclusions reached as a result of this study are as follows:

1. The flow field presented by the water table correlates well with $\gamma = 2.0$ gas theory for strong interactions up to normal Mach No. disturbances of 2.5.

2. The maximum thrust loss (based upon water table data) due to the aerodynamics of the nozzle-extension-to-nozzle connection is 0.105 percent.

3. Overheating of the downstream portion of the nozzle extension may be attributable to loss in coolant gas effectiveness incurred by large dumping at the first openings, thereby reducing flow downstream.

4. The controlling feature of the flow field past the test geometry is believed to be the separation point at the beginning of the manifold radius. The position of this point is determined by the upstream wall currents generated by circulation and flow out of the first secondary injection gap of the transition shingle.

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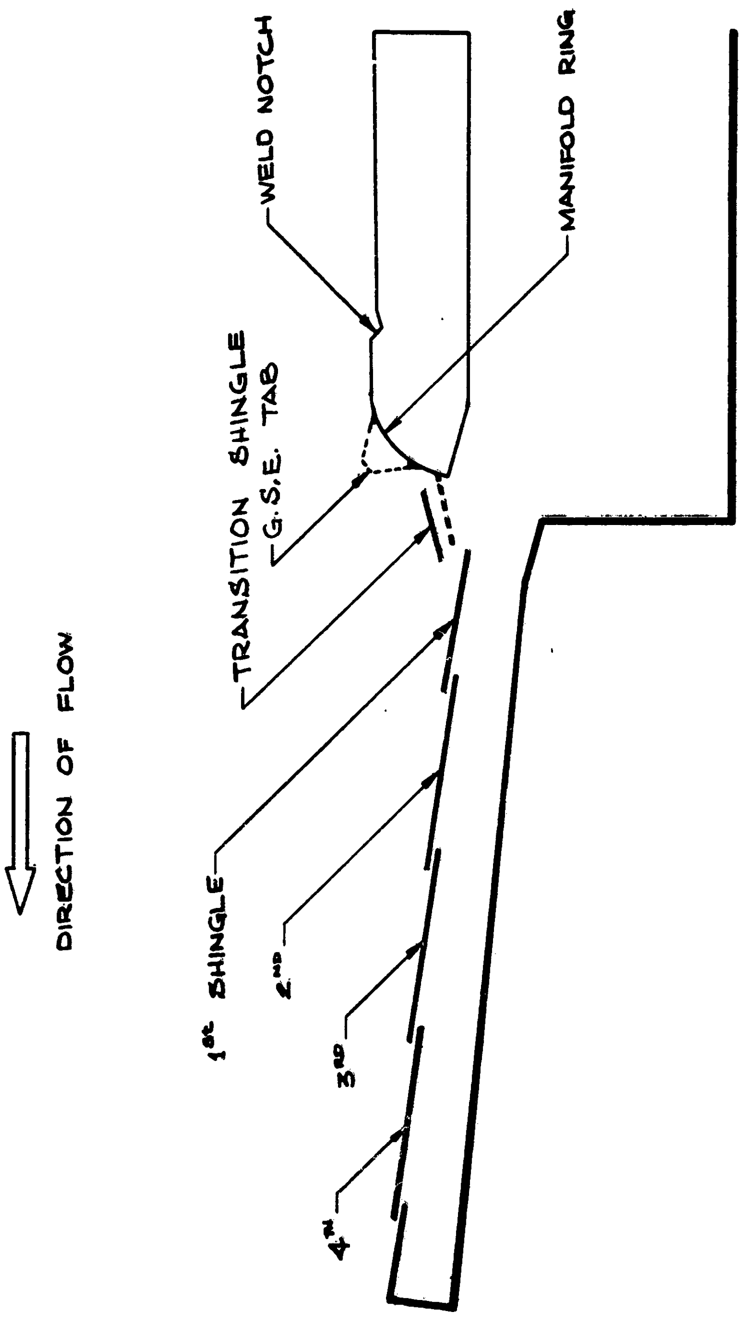

Figure 2. Water Table Model, Plan View

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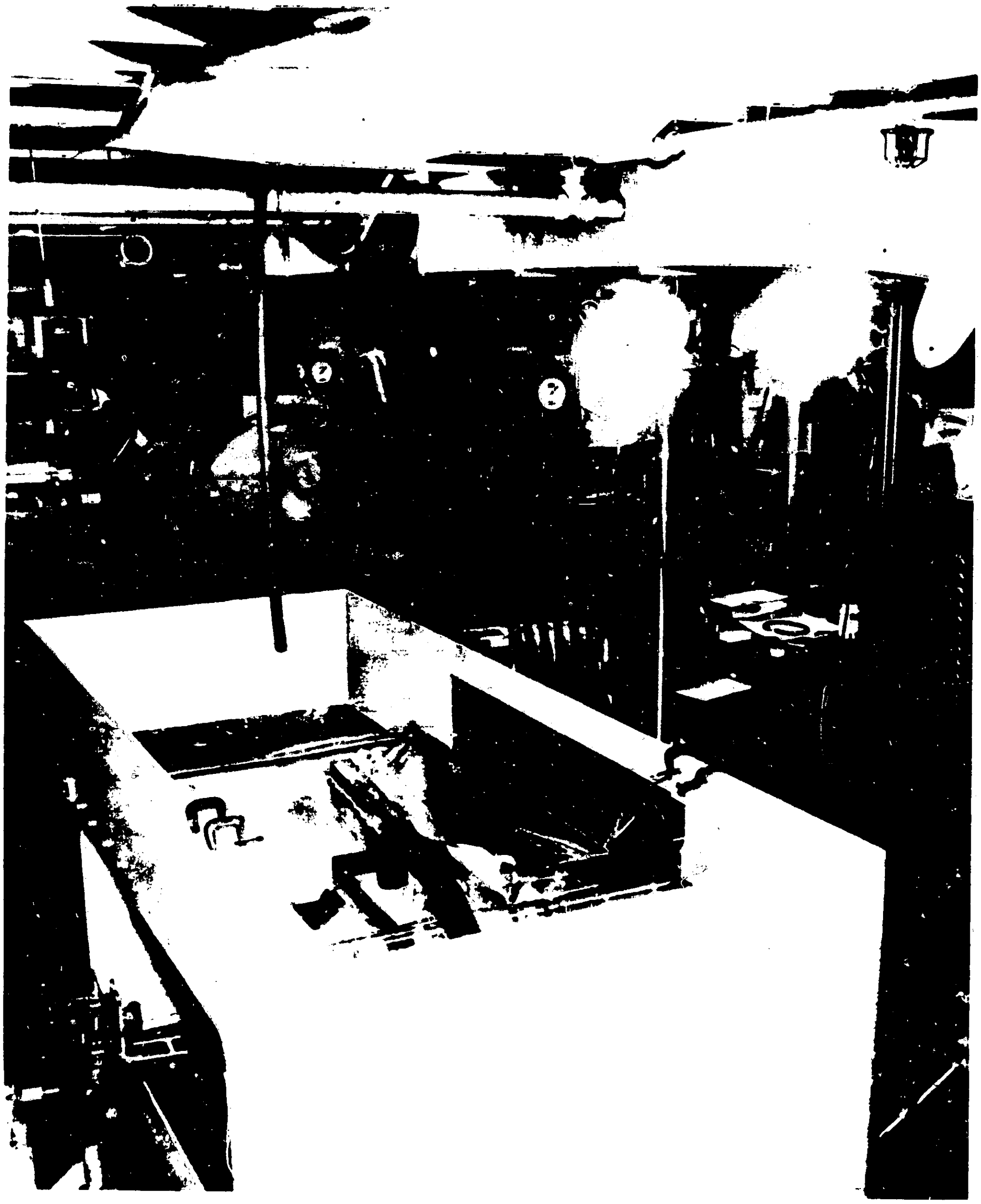

Figure 3. Water Table Facility

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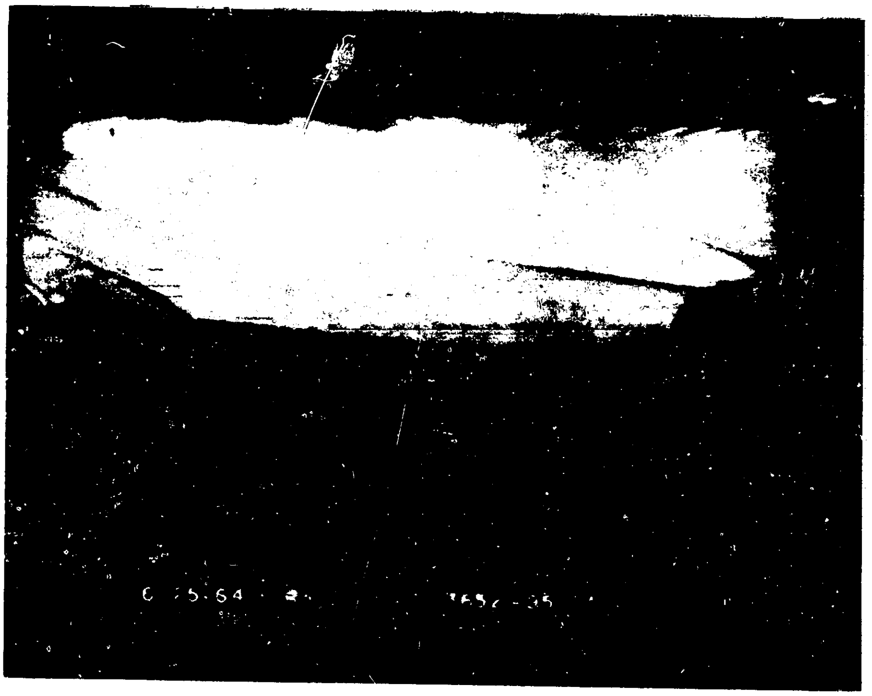

Figure 4. Simulated Gas Flow Past Present Nozzle Section

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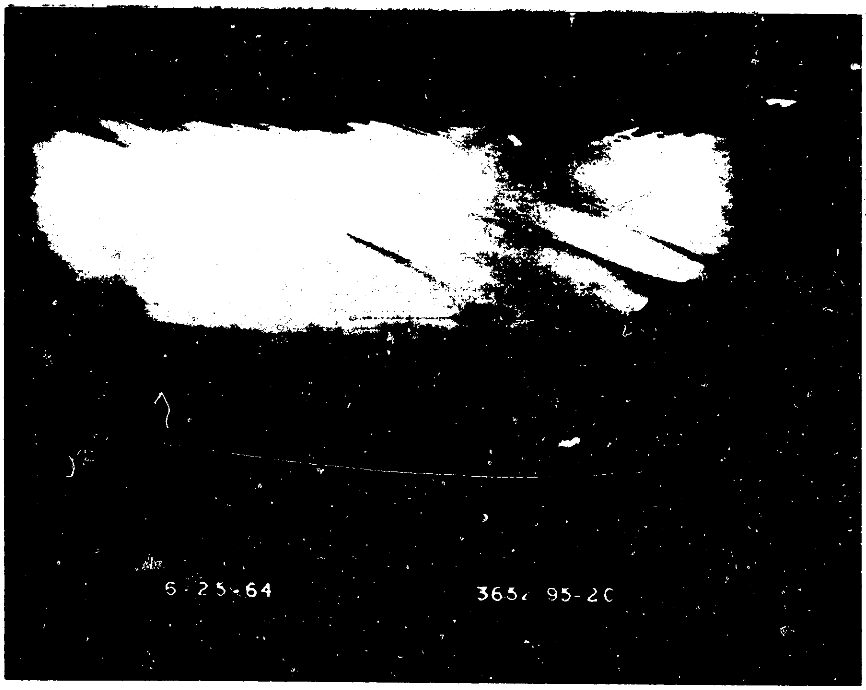

Figure 5. Simulated Gas Flow Past Present Nozzle Section With Secondary Injection

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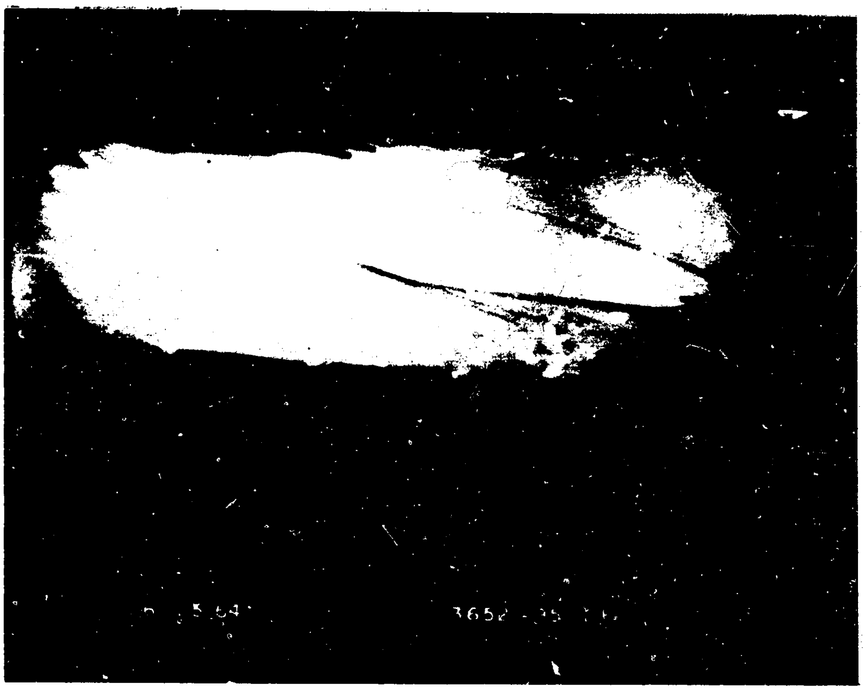

Figure 6. Simulated Gas Flow Past Nozzle Section With Modified Transition Shingle

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Figure 7. Simulated Gas Flow Past Nozzle Section With GSE Tab

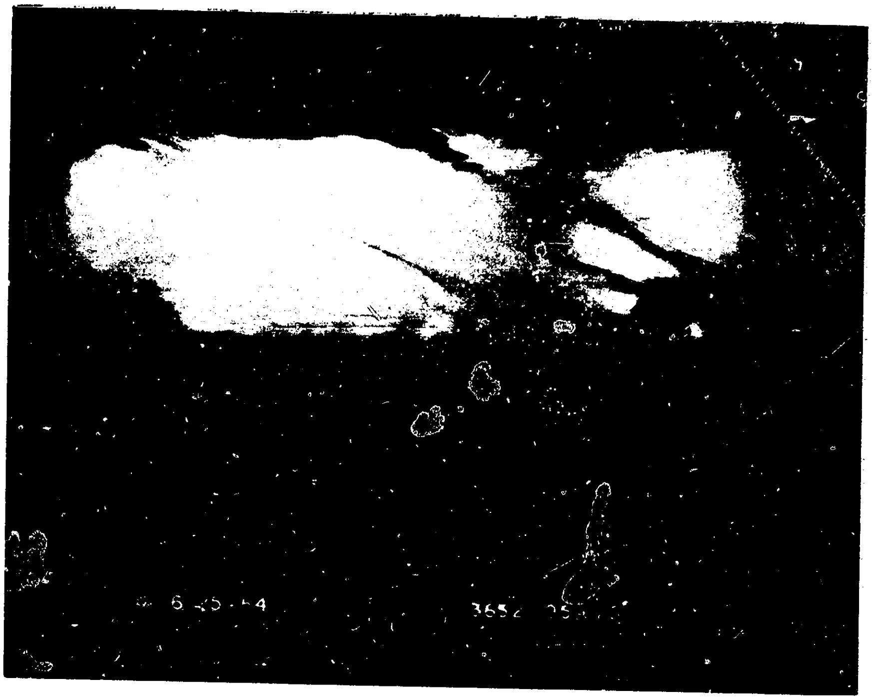

Figure 8. Simulated Gas Flow Past Nozzle Section With GSE Tab and Secondary Flow

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Figure 9. Simulated Gas Flow Past Nozzle Section With Modified Transition Shingle

[redacted]

Figure 10. Simulated Gas Flow Past Nozzle Section With Modified Transition Shingle

5. Losses at the transition are created from oblique shocks, which are required to turn the flow back parallel to the wall after expansion about the manifold radius.

6. The secondary gaps on the upstream and downstream sides of the transition shingle should be reduced in size so that these areas are commensurate with the other shingle gaps. This is based on the belief that too much coolant is being injected in the initial nozzle extension section which appears to be protected by natural stream separation.

7. A small amount of cross-stream flow should be allowed to remain through the gap between the manifold and the transition shingle. This is to cause early separation and to inhibit stream turning around the manifold radius.

8. Any protuberance in the mainstream is detrimental to performance and should be eliminated.

BUZZ INSTABILITIES

A special study was conducted to explain the 500-cps buzz instability (discussed in Volume 2, Book 2.) which first occurred on injector U/N 082. The following conclusions were reached.

1. The tendency to buzz increases with increasing LOX impingement angle.

2. The tendency to buzz is greater with LOX doublets than with LOX triplets. The addition of a small showerhead to the doublets (such that they became triplets) did not have a significant effect on the buzz.

3. The tendency to buzz is decreased by canting the LOX fans away from the radial baffles.

4. The tendency to buzz is decreased by the addition of a fuel ring groove and circumferential baffle dams.

5. The addition of LOX splitters installed in the axial feed holes and extending to the oxidizer ring does affect buzz. However, the degree of effectiveness is inconsistent, and it is not clear whether hydraulic impedance or LOX fan characteristics are involved.

A study of the hydraulic characteristics of the injector elements as a possible source of buzz-type instabilities was also undertaken. High-speed motion pictures taken at the hydrodynamics medium flow bench of water-flowed impinging doublets and triplet orifices were reviewed. The frequency of the waves formed by the intermittent disintegration of the liquid jets (Fig. 11) was determined by counting the number of waves between frames. These frequencies, which are a function of injection velocity and impingement angle, are being determined for the injector elements used on F-1 injectors. A correlation will be made between these wave frequencies and the F-1 buzz frequencies of 400 and 500 cps.

FEED SYSTEM FREQUENCIES

An intensified effort was made to determine empirically the source of feed system resonance with the combustion process. All of the propellant orifices in a flat-face steel injector were brazed shut, and the injector was installed in a solid-wall chamber. The feed systems were filled with water and pressurized. A high-pressure pulse was introduced into an inlet and between the

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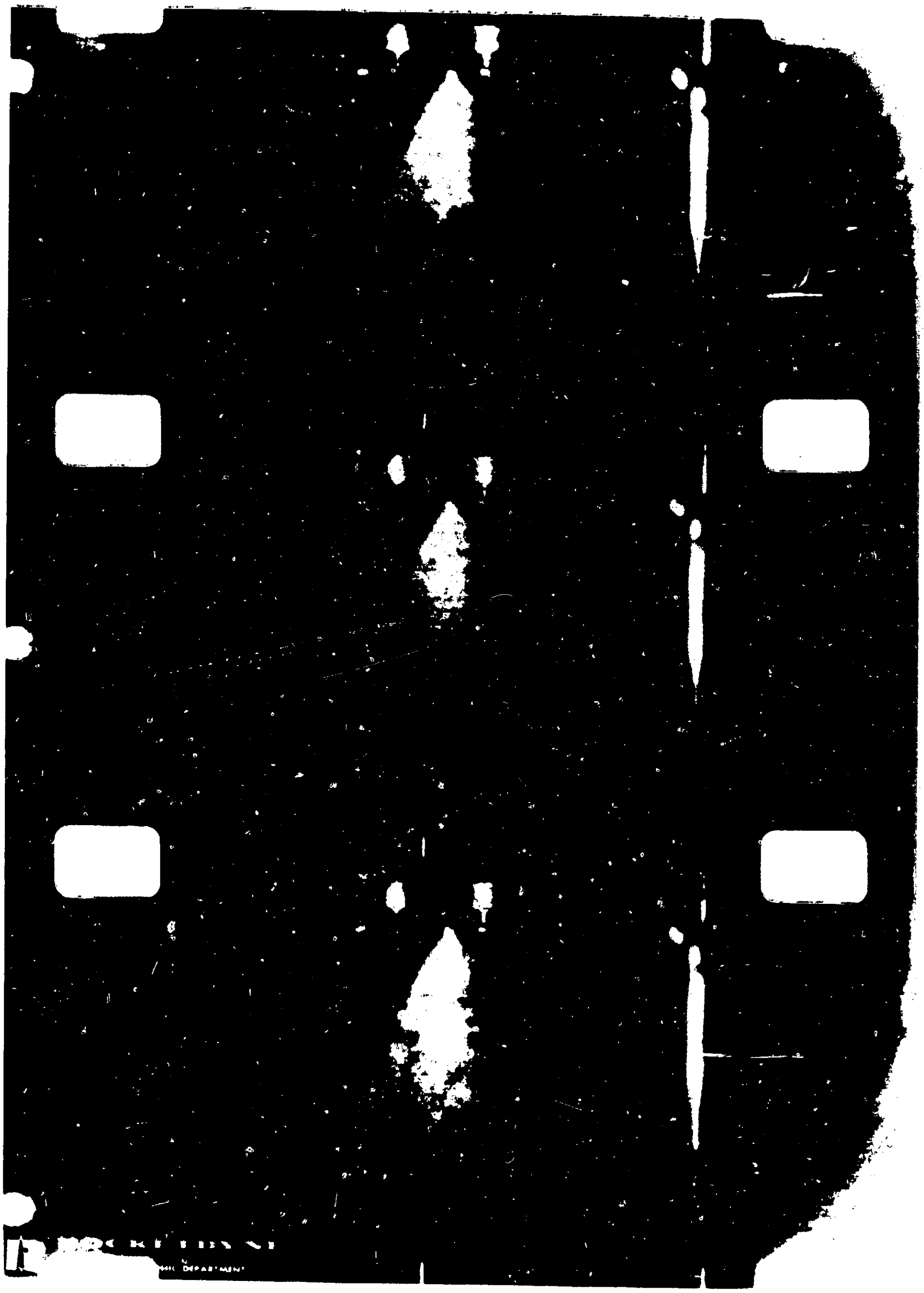

Figure 11. Intermittent Disintegration of Liquid Jets

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inlets, through an explosive pulsing unit. High-response Photocon transducers were used to record the pressure fluctuations within the fluid cavities.

The predominant frequency encountered in the fuel system was between 5000 and 6000 cps. These frequencies were attributed to tap cavity resonance, as it was found that fuel injection pressure taps were not flush-mounted.

The second most predominant frequencies, corrected for acoustic velocities in RP-1, were between 280 and 290 cps and were out of phase across the inlets. There was significant power in the range between 520 and 530 cps, but the phase relationship was inconsistent.

Data received from the pulse tests on the LOX side were too low and no predominant frequencies could be determined.

A DIGITAL MODEL FOR PREDICTION OF PROPELLANT DISTRIBUTION

A digital program that predicts propellant distribution for a ring-type injector from the geometry and fluid properties was developed. The effects of splitters also were determined in anticipation of their optimum deployment. The program's output yields the flowrate through each individual orifice plus flowrates and pressures internal to the injector. The method was applied first to typical F-1 injectors. The analytically predicted injector flow distribution correlated well with the experimental data. This analytical approach is now in use as a design guide for F-1 injectors to provide an even propellant distribution, and, as a result, improved injector performance. The conclusions reached as a result of this study are as follows:

1. The flow distribution of an injector can be analytically determined by use of a digital program.
2. The axial feed hole kinetic head effects are important in determining F-1 injector flow distribution.
3. A mismatched condition exists between LOX and fuel flow distributions in the present F-1 injectors.
4. Splitters affect the orifice area-to-feed hole area ratio, which is an important factor in the total flowrate of a ring section.
5. An area ratio of 0.5 (orifice-to-feed hole) for each section is desirable to distribute the flow properly.

Figures 12 through 14 show the normalized flowrates of the analytical and empirical methods for the outer LOX rings of an F-1 injector.

The results from this study clearly show that the kinetic head of the axial feed hole flow significantly affects the orifice flowrate distribution (Fig. 15). The high-flow orifices are those which are directly below axial feed holes. Because of this effect, the fuel distribution is mismatched with the LOX for the desired mixture ratio. This was predicted by the analytical results and confirmed by test measurements. The construction of the F-1 injector (Fig. 16) causes the LOX axial feed passages to lie between those of the fuel. As a result, where there is high fuel flow, there is low LOX flow, and vice-versa.

The effect of the splitters, as determined analytically and later confirmed by test measurement, was to starve ring sections whose orifice area-to-feed passage area varied widely. This caused drastic variations in flow distribution. Figure 17 describes one of the more severe cases. The middle

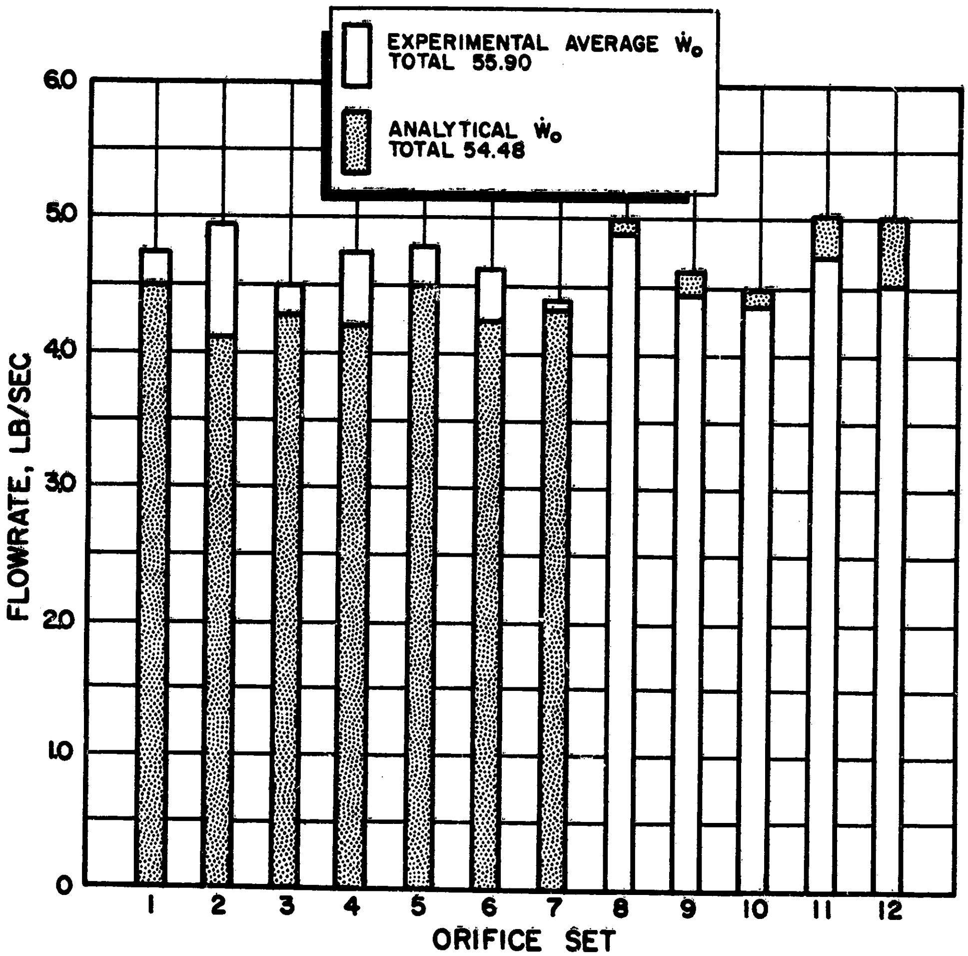

Figure 12. Ring No. 1, -57, LOX Injector, Type 84D

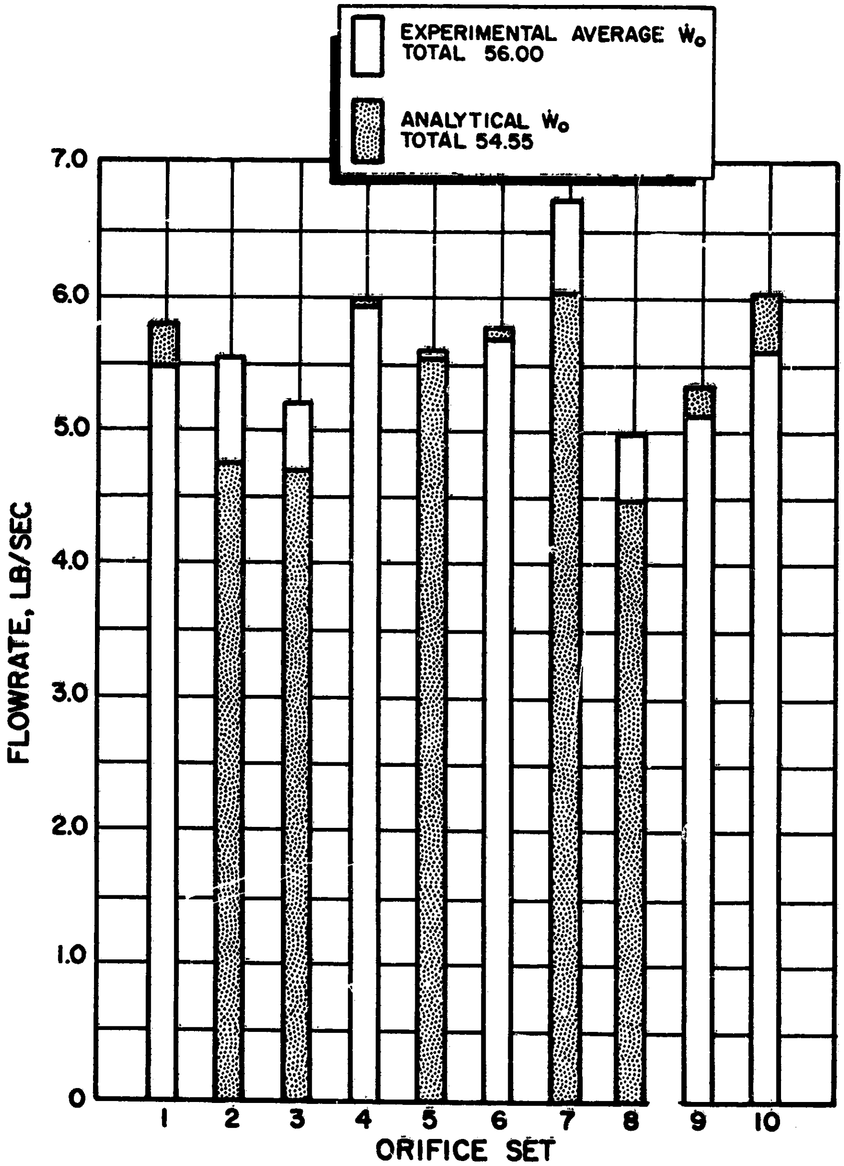

Figure 13. Ring No. 3, -49, LOX Injector, Type 84D

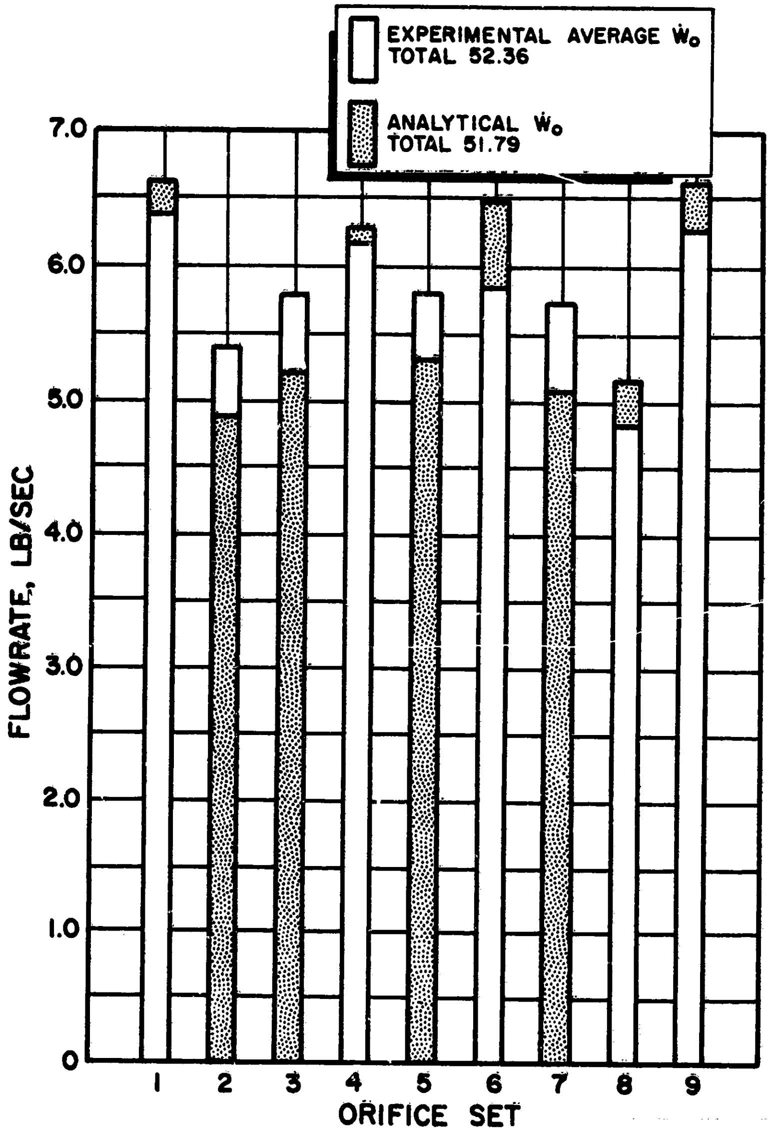

Figure 14. Ring No. 4, -45 LOX Injector, Type 84D

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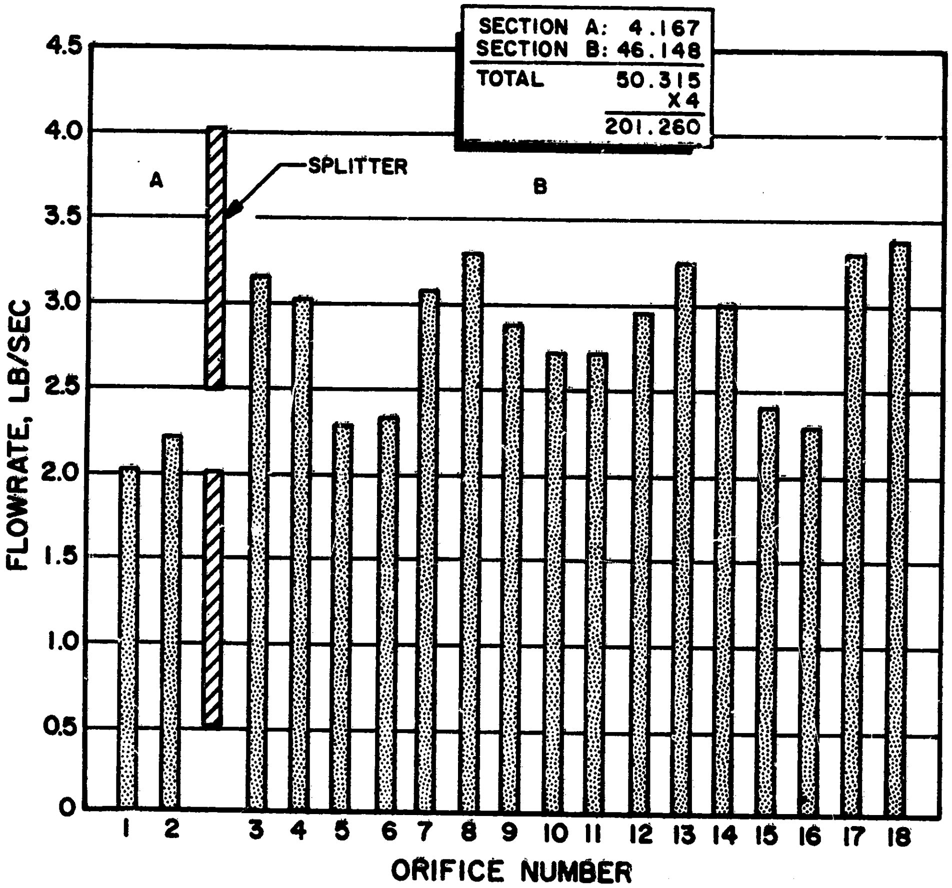

Figure 15. LOX Flow Distribution, Ring 23, Injector Type 84D

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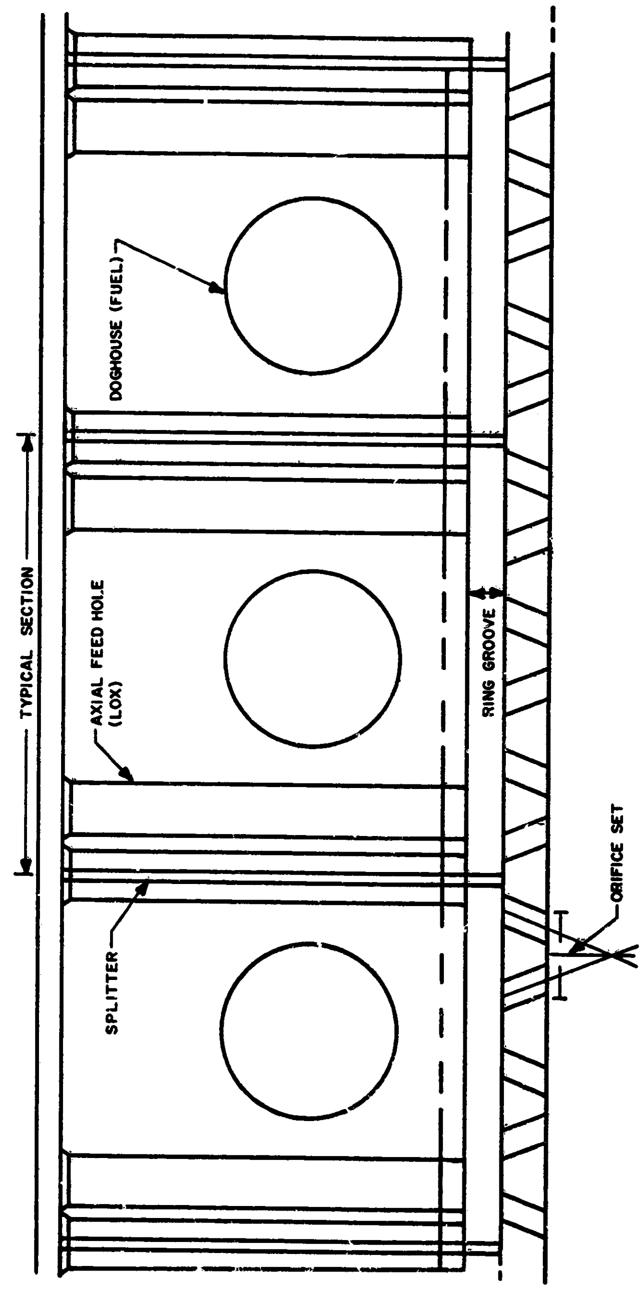

Figure 16. Slice of Typical LOX Ring

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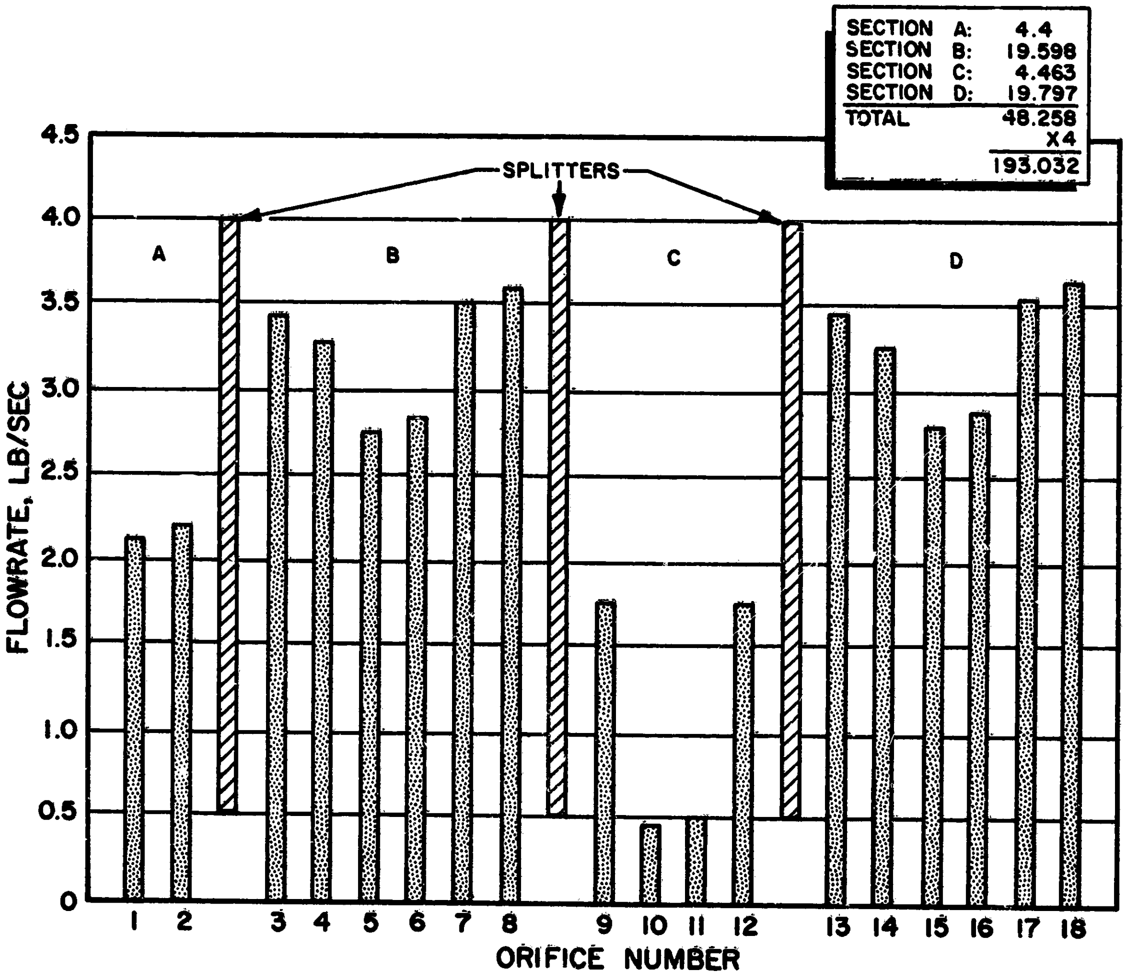

Figure 17. LOX Flow Distribution, Ring No. 23, Injector 92

compartment has a very high A_o/A_{fp} ratio because of the particular splitter deployment. This specific case has been corrected. It was found that an area ratio of 0.5 or lower provides an even flow distribution between and within compartments, which, in turn, properly distributes the flow to the orifices.

COMPONENT TEST ANALYSIS

Testing at the high-pressure, component test stand 2A-1 was conducted to evaluate the following injector concepts, and for analytical studies:

1. Flowmeter correlation study
2. Evolution of the FRT injector
3. Concepts evolved from FRT testing
4. Wall gap
5. Hydraulic modifications
6. Rotated spray fans
7. Reversed 5U orifice pattern
8. Concentric tube
9. Multicompartment baffled injector

A brief description of injector designs and a general test summary are presented in the following paragraphs. Photographs and injector description sheets are given and a detailed summary of each test is given in Table 1 .

FLOWMETER CORRELATION STUDY

Six tests were conducted on the PFRT injector F1002 in a tubular wall chamber as part of the flowmeter correlation effort on the EFL component test stand 2A-1. Previous surveillance of component test data and engine

TABLE 1

INJECTOR TEST SUMMARY

Tests:	219 through 222 (2A-1) 7-10-64
Injector Type:	5867 J3, U/N X056, identical to the configuration fired on tests 212 through 215
Objective:	Evaluation of the damping characteristics of this configuration
Test Results:	Four tests conducted in tubular wall thrust chamber 20-14 were bombed and damped in 22, 39, 20, and 14 milliseconds; five exit manifold and one 2-to-1 splice leaks were incurred; 400-cps buzzing was not present, but there was evidence of 400 to 500 cps oscillations in feed system parameters for the first two tests
Tests:	223 through 226 (2A-1) 7-11-64
Injector Type:	5881 M3, U/N 084, A_{ot}: 61.4, A_{ft}: 85.1, V_o (1500 K): 133.0, V_f (1500 K): 55.7
Description:	5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter fuel doublets at 30 degrees, except for those in the outer ring, which are 0.228-inch-diameter at 40 degrees; 0.209-inch-diameter LOX orifices at 40 degrees in outer ring; 0.242-inch-diameter elsewhere at 40 degrees, except next to radials the adjacent half angle is 28 degrees 12 minutes; 40 baffle dams (32 + 8), deep LOX grooves, fuel port isolation tabs, no film or body coolant orifices, 314 LOX splitters, 3.2 percent wall coolant, rotated baffles, outer fuel ring orificed for 70-percent flow
Objective:	Investigation of the effect of the canted fans on stability and performance
Test Results:	In four tests in tubular wall thrust chamber 20-8, two bomb disturbances damped in 23 and 45 milliseconds; four transverse tube cracks and one burnout were incurred during the tests; 400-cps buzzing was evident only in test 223
Tests:	227 through 230 (2A-1) 7-15-64
Injector Type:	5867 J3, U/N: 092, A_{ot}: 58.8, A_{ft}: 85.1, V_o (1500 K): 138.9, V_f (1500 K): 55.6
Description:	FRT-type, baffled (13x3 wide-base, fuel-cooled) modified 5U, 0.281-inch-diameter fuel doublets at 30 degrees (outer ring is 0.228-inch-diameter at 40 degrees, and orificed to half flow in the axial feed holes); 0.242-inch-diameter LOX doublets at 40 degrees (outer LOX ring is 0.209-inch-diameter at 40 degrees, LOX orifices next to baffles are 0.209-inch-diameter at 40 degrees); 314 LOX splitters, 40 baffle dams (32 + 8), no film or body coolant orifices, 2.3 percent wall coolant, rotated baffles
Objective:	Investigation of hardware repeatability; comparison of results of these tests to those on U/N X056, Type 5867 J3 (tests 212 through 215, and 231 through 233)

TABLE 1

(Continued)

Test Results:	Four tests conducted in tubular wall thrust chamber 20-14 with dome 009R at chamber pressures ranging from 1061 to 1114 psi and mixture ratios from 2.22 to 2.53; the average c* efficiency was 92.6 percent, yielding an average equivalent engine specific impulse of 259.6 seconds; 13.5-grain bombs were employed in tests 229 and 230 and an RCC was incurred in 229; posttest inspection revealed that the baffles were bent clockwise and 5 to 10 percent of the thrust chamber tubes were partially collapsed near the injector end ring
Frequency Analysis:	In test 230, two distinct resurges were evident 17 and 42 milliseconds after the bomb detonation; 400 to 500 cps oscillations were evident in nearly all parameters between resurges; two resurges, 11 and 24 milliseconds after bomb detonation occurred in test 230; again 400 to 500 cps oscillations were apparent between resurges; overall damp times were 58 and 37 milliseconds, and there was no evidence of any type of buzzing in any of the runs
Tests:	231 through 233 (2A-1) 7-16-64 and 7-17-64(2)
Injector Type:	5867 J3, U/N: X056, identical description as U/N 092, tests 227 through 230
Objective:	Performance check and comparison for repeatibility
Test Results:	Three tests conducted in tubular wall thrust chamber 20-8 and dome 009R at chamber pressures ranging from 1097 to 1118 psi and mixture ratios from 2.36 to 2.41; the average c* efficiency was 91.4 percent, yielding an average equivalent engine specific impulse of 257.5 seconds; two 13.5-grain bombs were employed and all tests achieved program duration; there was no apparent chamber damage, but there was some lack of carbon in the injector end; five bypass plugs worked loose and were found in the injector fuel doghouses
Frequency Analysis:	In test 232, the system took about 73 milliseconds to damp the bomb disturbance, but no distinct resurges were evident; 400 to 500 cps oscillations (1000 cps in RCC's) were present for most of the instability and a 400-cps buzz at 200 psi peak to peak was in evidence throughout most of the test; in test 233, the system damped in 8 milliseconds, and no buzzing was evident
Tests:	234 through 238 (2A-1) 7-18-64 (2) 7-20-64 (2)
Injector Type:	5882 N3, U/N: X005, A_{ot}: 49.2, A_{ft}: 85.1, V_o (1500 K): 166.1, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), similar to U/N 082, Type 5833 K3, 0.281-inch-diameter fuel doublets at 30 degrees, (except outer ring, 0.228-inch-diameter at 40 degrees), 0.209-inch-diameter LOX doublets at 56 degrees 24 minutes (fans canted away from baffle by 4 degrees 6 minutes, the -9 LOX ring orifices are

TABLE 1

(Continued)

Description: (Continued)	0.209-inch-diameter at 40 degrees, 314 LOX splitters, 164 fuel ring dams, deep fuel ring grooves, outer ring orificed for 70-percent flow, no film or body coolant orifices, 3.2 percent wall coolant
Objective:	Performance check and investigation of 500-cps buzzing
Test Results:	The four tests were successful, test 237, however, was a sequence malfunction, as the LOX main valve failed to open; c* efficiency average 92.8 percent, yielding an equivalent engine specific impulse of 259.8 seconds; two bomb disturbances were damped in 7 milliseconds with no indications of resurging; slight buzzing at 500 cps was discernible above the noise level in fuel parameters, but amplitudes were very low
Tests:	239 (2A-1) 7-21-64
Injector Type:	5869 03, U/N: X035, A_{ot}: 41.9, A_{ft}: 86.2, V_o (1500 K): 195.0, V_f (1500 K): 55.0
Description:	5U baffled (3-compartment uncooled), 0.281-inch-diameter fuel doublets at 30 degrees, outer ring is 0.228-inch-diameter at 40 degrees, 0.159-inch-diameter LOX triplets at 40 degrees, no film or body coolant orifices, LOX triplets next to the baffles plugged, 4.4 percent wall coolant, 147 LOX splitters
Objective:	Investigation of the effect of the hydraulic modifications on stability
Test Results:	13.5-grain bomb induced an instability which persisted for 775 milliseconds; the baffle at the 9 o'clock position was blown off the injector face
Frequency Analysis:	The predominant frequency was between 450 and 500 cps with phase relationships always indicating out of phase and sometimes spinning conditions in the chamber; amplitudes were high (greater than 1000 psi peak to peak) with wave forms similar to those of a flat-face instability; a review of the films indicated that the baffle probably came off either in transition or in cutoff, rather than in mainstage
Tests:	240 (2A-1) 7-22-64
Injector Type:	5879 F3, U/N: X002, A_{ot}: 58.8, A_{ft}: 85.1, V_o (1500 K): 138.9, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch- diameter fuel doublets at 30 degrees, (outer ring is 0.228-inch-diameter at 40 degrees), 0.209-inch-diameter LOX doublets in outer LOX ring and next to baffles at 28 degrees 12 minutes (20 degrees for LOX ring just inside inner circumferential baffle), remainder are 0.248-inch-diameter at 28 degrees 12 minutes; 314 LOX splitters, 156 fuel ring dams, 24 baffle dams, 4.6 percent wall coolant (no film or body coolant crifices)
Objective:	Investigation of the effect of the canted fans on the 500-cps buzz

TABLE 1

(Continued)

Test Results:	No bomb was employed; the system phased into a 500-cps buzz shortly after 90 percent chamber pressure, and the oscillations persisted until cutoff; as in the last test, the baffles were again burned; c* efficiency was 91.7 percent
Tests:	241 (2A-1) 7-23-64
Injector Type:	5840 V, U/N: X012, A_{ot}: 47.30, A_{ft}: 28.4, V_o (1500 K): 173.0, V_f (1500 K): 167.0
Description:	Baffled (11x3 uncooled), 0.125-inch-diameter fuel doublets impinging subface at 34 degrees (outer ring is 0.125-inch-diameter showerheads canted 20 degrees toward the chamber wall), 0.0937-inch-diameter LOX doublets impinging subface at 34 degrees; 96 body coolant holes; spray fans rotated such that unlike impingement of fan tips does not occur; 16.75 percent wall coolant
Objective:	Investigation of the effect of the canted fans on stability
Test Results:	In a single checkout test, the system self-triggered 500 milliseconds after cutoff; the outer radial baffles were partially torn loose from the injector face
Frequency Analysis:	The instability frequency ranged from 300 to 500 cps at moderate amplitude (500 to 700 psi peak to peak); phase relationships were not consistent
Tests:	242 (2A-1) 7-24-63
Injector Type:	5880 R, U/N: X018, A_{ot}: 51.0, A_{ft}: 28.75, V_o (1500 K): 150.0, V_f (1500 K): 165.0
Description:	Reverse 5U baffled (13x3 uncooled), 0.157-inch-diameter fuel doublets at 40 degrees matched to outboard 0.172-inch-diameter LOX triplets at 40 degrees; outer fuel ring is 0.1285-inch-diameter showerheads canted at 20 degrees toward the wall, 200 body coolant orifices at 0.052-inch-diameter, 11.6 percent wall coolant
Objective:	Investigation of the reverse 5U concept on stability
Test Results:	Single stable cutoff run was successful; however, deep erosions were incurred on all the radial baffles
Tests:	251 and 252 (2A-1), 8-3-64, 8-4-64
Injector Type:	5867 A3, U/N: 081, A_{ot}: 58.8, A_{ft}: 85.118, V_f (1500 K): 55.7, V_o (1500 K): 138.9
Description:	Similar to 084A type injectors, modified 5U, 13x3 baffled injector, 0.281-inch-diameter fuel doublets at 30 degrees, outer ring is 0.228-inch-diameter at 40 degrees, 0.242-inch-diameter LOX doublets at 40 degrees except along baffles and in outer ring which are 0.209-inch-diameter at 40 degrees; 314 LOX splitters; no film or body coolant holes, programmed baffles, fuel injection manifold tabs, outer fuel ring axial feed holes orificed for 50-percent flow

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TABLE 1

(Continued)

Objective:	Investigation of the damping characteristics of this injector in solid-wall chamber 13 with improved O-ring
Test Results:	The first test resulted in a fail-safe cutoff when the main LOX valve failed to open; in the second test the disturbance from a 13.5-grain bomb damped in 12 milliseconds without resurging and programmed cutoff was achieved after 2.2 seconds; the mixture ratio was high (2.65) and thrust chamber erosions in compartments 1, 4, 5, 6, and 8 were incurred
Tests:	253 (2A-1), 8-4-64
Injector Type:	5870 G3, U/N: X017, A_{ot}: 49.3, A_{ft}: 30.3, V_o (1500 K): 165.8, V_f (1500 K): 156.4
Description:	Modified 5U baffled (53x3 narrow-base, uncooled); outer fuel blanked off and covered with a circumferential baffle 4 inches long, all radial baffles are 3 inches long; 0.166-inch-diameter LOX triplets at 40 degrees, 0.196-inch-diameter fuel doublets at 40 degrees, hydraulic modification, 159 fuel ring dams, 215 LOX ring dams, no film coolant orifices, 104 body coolant orifices of 0.054-inch-diameter
Objective:	Evaluation of the damping characteristics with 53 baffle compartments and with a minimum of fuel in the outer zone
Test Results:	In a 1.1-second test, about 1 inch of the thrust chamber was nearly uniformly burned away for the entire length of the combustion zone; several holes burned through the thrust chamber such that chamber pressure was decaying prior to cutoff; injector was in relatively good shape but the outer circumferential and nearly all radial baffles were burned
Frequency Analysis:	Special analysis techniques required to analyze the instability; the bomb detonated during the sequence (cutoff) and the chamber pressure parameters appeared to damp very quickly; however, the accelerometers indicated that the instability did not damp and some very low-amplitude fluctuations persisted in the LOX and fuel measurements
Tests:	243 through 248 (2A-1) 7-29-64, 7-30-64 (4), 7-31-64
Injector Type:	5883 M3, U/N: X056, A_{ot}: 60.1, A_{ft}: 85.0, V_o (1500 K): 136.0, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled); 0.281-inch-diameter fuel doublets at 30 degrees; outer fuel ring is 0.228-inch-diameter at 40 degrees, LOX system (injection) consists of 0.242-inch-diameter doublets with following exceptions: outer ring and those orifices adjacent to circumferential baffles are 0.209-inch-diameter at 40 degrees, orifice facing radial baffle is 0.209-inch-diameter at 20 degrees, orifice facing away from radial baffle is 0.242-inch-diameter at 28.2 degrees, outer fuel ring

[redacted]

TABLE 1

(Continued)

Description: (Continued)	is orificed for 70-percent flow, 40 baffle dams (32 + 8), 164 fuel ring, groove dams, 314 LOX splitters, 3.2 percent wall coolant (all film and body coolant orifices plugged), rotated baffles
Objective:	To determine if increased canting of the fans will benefit stability
Test Results:	Nine bombs were damped in less than 13 milliseconds in tubular wall thrust chamber 20-14; the four long bombs employed did not produce a significant disturbance
Frequency Analysis:	410 cps buzzing was present in all tests, with amplitudes ranging from 50 to 300 psi peak-to-peak, out-of-phase conditions existing across the oxidizer dome
Tests:	249 and 250 (2A-1) 8-1-64
Injector Type:	5882 N3, U/N: X005, A_{ot}: 49.2, A_{ft}: 85.1, V_o (1500 K): 166.1, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled); 0.281-inch-diameter fuel doublets at 30 degrees, outer fuel ring 0.228-inch-diameter at 40 degrees, 0.209-inch-diameter LOX doublets at 56.4 degrees, (LOX orifice facing baffle is at 20 degrees half angle); 164 fuel ring groove dams, deep fuel ring grooves, the -9 LOX ring has 0.209-inch-diameter doublets at 40 degrees, no film or body coolant holes; 3.2 percent wall coolant
Objective:	Investigation of 500-cps buzzing
Test Results:	Two successful tests conducted in tubular wall thrust chamber 20-8 and the two bomb disturbances were damped in 11 and 8 milliseconds
Frequency Analysis:	490-cps buzzing was predominant in the RCC's and fuel injection measurements in both tests; amplitudes were about 300 psi peak to peak in fuel injection parameters and about 200 g peak to peak in the accelerometers with out-of-phase conditions existing across the LOX inlets; there was a disturbance for about 30 milliseconds at 400-g amplitude in the RCC's as the system went into mainstage
Tests:	254 (2A-1) 8-6-64
Injector Type:	5872 H3, U/N, 074, A_{ot}: 71.46, A_{ft}: 26.4, V_o (1500 K): 114.3, V_f (1500 K): 179.5
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), outer fuel and LOX ring plugged, 0.159-inch-diameter fuel doublets at 40 degrees, 0.221-inch-diameter LOX triplets at 40 degrees, programmed baffles, no film or body coolant orifices, LOX side baffles; no LOX splitters, fuel injection manifold tabs, or fuel port inserts; 6.63 percent wall coolant
Objective:	To determine if plugged outer rings would cause a small fuel orifice baffled injector to damp a bomb disturbance

TABLE 1

(Continued)

Test Results:	Bomb-induced instability, which persisted for 750 milliseconds, and the outer rings of the injector were badly eroded
Frequency Analysis:	The mode was characterized by 490-cps, out-of-phase oscillations at about 1000 psi peak to peak in amplitude; essentially no change from a small fuel orifice 13x3 baffled injector without the plugged outer rings
Tests:	255 (2A-1) 8-8-64
Injector Type:	5869 03, U/N: X035, A_{ot}: 41.9, A_{ft}: 86.2, V_o (1500 K): 195.0, V_f (1500 K): 55.0
Description:	5U baffled (13x3 wide-base, uncooled) 0.281-inch-diameter fuel doublets at 30 degrees, outer ring is 0.228-inch-diameter at 40 degrees, 0.159-inch-diameter LOX triplets at 40 degrees, no film or body coolant orifices, six igniter buttons blanked, LOX triplets next to baffles plugged, 4.4 percent wall coolant, no hydraulic modifications except 147 LOX splitters
Objective:	To determine if removal of the hydraulic modifications has any effect on dynamic stability
Test Results:	Bomb-induced instability which did not damp; the injector was relatively undamaged, but the O-ring was badly extruded, a crack developed around a fuel manifold boss, and the dome failed in the vicinity of the clevis
Frequency Analysis:	The data were similar to that of the previous instability on this injector; the predominant frequency was 475 to 490 cps at 1000 to 2000 psi peak to peak with out-of-phase conditions existing across the chamber, oxidizer dome, and fuel manifold; the instability persisted for 772 milliseconds
Tests:	256 (2A-1) 8-10-64
Injector Type:	58[illegible] R, U/N: X018, A_{ot}: 51.0, A_{ft}: 28.75, V_o (1500 K): 150.0, V_f (1500 K): 165.0
Description:	Reverse 5U baffled (13x3 slim-base, uncooled) 0.157 fuel doublets, outer ring consists of 0.1285-inch-diameter showerheads directed 20 degrees toward the wall; 0.172-inch-diameter LOX triplets; 200 body coolant holes of 0.052-inch-diameter; 11.6 percent wall coolant
Objective:	To investigate the effect of oxidizer in the outer periphery on stability
Test Results:	A 13.5-grain charge induced on instability which caused rough combustion cutoff; the radial baffles were severely burned, and the O-ring was destroyed
Frequency Analysis:	The instability was cyclic, in phase, with moderate amplitudes at about 250 cps; the wave form was peaked, similar to that of the 200-cps H-1 oscillations

TABLE 1

(Continued)

Tests:	257 and 258 (2A-1) 8-11-64
Injector Type:	5884 F3, U/N: X002, A_{ot}: 61.05, A_{ft}: 85.0, V_o (1500 K): 133.8, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled) 0.281-inch-diameter fuel doublets at 30 degrees (outer ring is 0.228-inch-diameter at 40 degrees); 0.242-inch-diameter LOX doublet 56 degrees 24 minutes with 0.625-inch-diameter showerhead; the LOX doublets in the outer ring end next to all baffle surfaces are 0.209-inch-diameter at 28 degrees 12 minutes half angle (20 degrees half angle in -9 ring), no film or body coolant orifices, 4.6 percent wall coolant, 314 LOX splitters, 156 fuel ring dams, 32 baffle dams, canted fans next to radial baffles as in U/N 082B
Objective:	To investigate the effect of the small LOX showerhead on the buzz mode
Test Results:	In test 257, the cutoff signal occurred just before the main fuel valve reached the open position; the system never reached stable mainstage but 400- and 500-cps buzzing was present; in test 258, the mixture ratio was high and the ends of the baffles were eroded, however, there was no buzzing in the chamber parameters; there were indications of 400 to 500 cps oscillations in the fuel measurements
Tests:	259 (2A-1) 8-13-64
Injector Type:	5828 V, U/N: F1002, A_{ot}: 53.3, A_{ft}: 62.3, V_o (1500 K): 153.5, V_f (1500 K): 75.7
Description:	5U baffled (13x3 wide-base, fuel-cooled); 0.228-inch-diameter fuel doublets at 40 degrees, 0.185-inch-diameter LOX triplets at 40 degrees, 0.1285-inch-diameter film and 0.076-inch-diameter body coolant orifices, ASME orifices in all but outer ring rotated baffles, hydraulic modification 2
Objective:	Re-evaluation of the damping characteristics of the PFRT injector
Test Results:	At 1095 psi chamber pressure and 2.41 mixture ratio, a 13.5-grain charge induced an instability which persisted for 55 milliseconds; the mode was typical for this type of injector: resurging with 500-cps oscillations
Tests:	260 through 266 (2A-1) 8-14-64 (3) 8-15-64
Injector Type:	5885 P3, U/N: X053, A_{ot}: 61.8, A_{ft}: 85.0, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled): basically an 084C type injector (0.242-inch-diameter LOX doublets with 0 209-inch-diameter outer ring, 0.281-inch-diameter fuel doublets with 0.228-inch-diameter outer ring), but LOX orifices next to radial baffles are 0.250-inch-diameter at 28 degrees 12 minutes half angle to cant the LOX fan away from the baffle surface; 3.2 percent wall coolant, 32 baffle dams, 302 LOX splitters, outer ring orificed for 70 percent flow, rotated baffles

TABLE 1

(Continued)

Objective:	Investigation of the effect of the enlarged orifices next to the baffles on stability and performance
Test Results:	Facility malfunctions resulted in only five of the seven tests being successful, with all four bomb disturbances damping in less the 14 milliseconds; all tests were characterized by an unusual roughness during transition and some 400-cps oscillations were present in CG1A during mainstage; the equivalent engine performance was about 1 second lower than the 084C type
Tests:	267 (2A-1) 8-17-64
Injector Type:	5869 R, U/N: X035, hydraulic modification 1, A_{ot}: 41.9, A_{ft}: 86.20, V_o (1500 K): 195.0, V_f (1500 K), 55.0
Description:	5U baffled (3-compartment, uncooled), 0.281-inch-diameter fuel doublets at 30 degrees except for outer ring which consists of 0.228-inch-diameter doublets at 40 degrees; 0.159-inch-diameter LOX triplets at 40 degrees, 38 LOX triplets next to baffle surfaces plugged, no film or body coolant orifices, 4.4 percent wall coolant
Objective:	Re-evaluation of the hydraulic modifications on stability (refer to tests 188 through 190, 239, and 255)
Test Results:	13.5-grain bomb induced an instability which caused rough combustion cutoff after 0.89 seconds of mainstage; the baffles were slightly bent and the dome inlet flange was eroded
Frequency Analysis:	The mode was predominantly 500-cps, high-amplitude, out-of-phase oscillations, accompanied by secondary higher frequency oscillations
Tests:	268 through 270 (2A-1) 8-19-64 to 8-20-64 (2)
Injector Type:	5886, U/N: X014, A_{ot}: 64.9, A_{ft}: 38.8, V_o (1500 K): 126.0, V_f (1500 K): 122
Description:	Coaxial baffled (21x3 square compartments cooled by coaxial elements); mixing accomplished by swirlers in the inner LOX tube, forcing LOX into the fuel being injected out of the outer tube; concentric elements are of lengths varying from 0 to 3 inches, scattered randomly across the injector face
Objective:	Further evaluation of the characteristics of the coaxial stream concept
Test Results:	Three runs conducted in solid-wall thrust chamber 1508 without a bomb; in the first test, the system self-triggered at 1144 psi chamber pressure and 2.87 mixture ratio, and an RCC was incurred; in the second and third tests, at near nominal conditions, 11 and 9 self-triggers occurred and both tests were eventually cut by the RCC device after 1.46 and 1.1 seconds, respectively; five injection tubes were eroded

TABLE 1

(Continued)

Frequency Analysis:	In the first test the system went into a 500-cps transverse mode with moderate chamber and feed system amplitudes but a low accelerometer level; in the second and third tests, the mode was not set up and damp times of the self-triggers varied from 5 to 198 milliseconds with a strong predominance of 500-cps oscillations; triangulation showed a random pattern in the location of the self-triggers
Tests:	271 and 272 (2A-1) 8-21-64
Injector Type:	5833 03, U/N: 082, A_{ot}: 49.2, A_{ft}: 85.08, V_o (1500 K): 170.0, V_f (1500 K): 56.0
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled) 0.281-inch-diameter fuel doublets at 30 degrees, outer fuel ring consists of 0.228-inch-diameter doublets at 40 degrees; 0.209-inch-diameter LOX doublets at 56 degrees 24 minutes except those orifices which face a radial baffle and those just inside inner can, which have a 20 degree half angle; 40 baffle dams (32 + 8), 165 fuel ring dams, no film or body coolant orifices
Objective:	To re-evaluate the buzzing characteristics of this injector without the splitters
Test Results:	Two tests conducted in solid-wall thrust chamber 1508 with chamber pressures and mixture ratios of 1059 and 1105 psi, and 2.19 and 2.38, respectively; there was no apparent hardware damage
Frequency Analysis:	There were low-amplitude oscillations of 500 cps in the fuel manifold parameters
Tests:	273 (2A-1) 8-22-64
Injector Type:	5887, U/N: X038, A_{ot}: 71.2, A_{ft}: 93.4, V_f (1500 K): 50.7, V_o (1500 K) 114.8
Description:	Flat-face injector with 0.281-inch-diameter fuel doublets at 30 degrees matched to inboard 0.242-inch-diameter LOX doublet at 40 degrees; no film or body coolant orifices, 6.2 percent wall coolant; outer fuel and outer LOX rings are plugged; no hydraulic modifications
Objective:	Investigation of the 084C-type orifice configuration with plugged outer rings as applied to a flat-face injector
Test Results:	A 13.5-grain bomb induced instability and the injector and dome were severely eroded; a pie-shaped section of injector was burned through into the dome cavity and the dome flange was burned out
Frequency Analysis:	The instability appeared to be a tangential mode at about 700 cps, but many higher frequencies were also present; amplitudes were moderate, much lower than for a normal flat-face instability

TABLE

(Continued)

Tests:	274 through 276 (2A-1) 8-25-64 (2), 8-28-64
Injector Type:	5885 P3, U/N: 092, A_{ot}: 61.8, A_{ft}: 85.0, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled): 0.281-inch-diameter fuel doublets at 30 degrees, outer fuel rings consist of 0.228-inch-diameter fuel doublets at 40 degrees, 0.242-inch-diameter LOX doublets at 40 degrees, outer LOX ring consists of 0.209-inch-diameter LOX doublets at 40 degrees, the LOX orifice adjacent to the radial baffle is enlarged to 0.250-inch-diameter at 28 degrees 12 minutes half angle; outer fuel ring is orificed for 70 percent flow, 302 crimped, spoon-type LOX splitters, 40 baffle dams, no film or body coolant orifices, 3.2 percent wall coolant
Objective:	Stability evaluation of the canted LOX fans
Test Results:	Three bombs were employed in a tube wall chamber (one in the second test and two in the third test); three tube ruptures occurred after the second test in compartments 7, 8, and 1, and the hardware had to be dismantled for repair; there was no damage incurred from the third test
Frequency Analysis:	In the second test (275) the bomb disturbance damped in 12 milliseconds without resurging; in test 276, however, the first disturbance was recorded 3.4 milliseconds after 90 percent chamber pressure, and damped in 9 milliseconds; 38 milliseconds later another disturbance occurred and damped in 54 milliseconds; both disturbances triangulated to the 7:00 o'clock location, where the long-duration quartz bomb was installed
Tests:	277 through 279 (2A-1) 8-28-64
Injector Type:	5885 P3, U/N: 092, A_{ot}: 61.8, A_{ft}: 85.0, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled); 0.281-inch-diameter fuel doublets at 30 degrees outer fuel rings consist of 0.228-inch-diameter fuel doublets at 40 degrees, 0.242-inch-diameter LOX doublets at 40 degrees, outer LOX ring consists of 0.209-inch-diameter LOX doublets at 40 degrees, the LOX orifice adjacent to the radial baffle is enlarged to 0.250-inch-diameter at 28 degrees 12 minutes half angle; outer fuel ring is orificed for 70 percent flow, 302 crimped, spoon-type LOX splitters, 40 baffle dams, no film or body coolant orifices, 3.2 percent wall coolant
Objective:	Investigation of fuel lead and dry jacket starting sequences and investigation of a leaking bomb boss as a source of self-triggering
Test Results:	Tests 277 and 278 were successfully fired in a tube wall chamber using a fuel rather than water prefill in the chamber; mainstage was achieved 2 to 3 times faster than normal (100 to 500 milliseconds rather than 350 to 400 milliseconds), but there were no excessive system vibrations; in the dry jacket start, the system again reached

TABLE 1

(Continued)

Test Results: (Continued)	stable mainstage successfully in about 100 milliseconds, but some water hammer effects were noticed in the fuel system; there was no excessive system vibration
Tests:	280 through 283, (2A-1) 8-31-64, 9-1-64 (3)
Injector Type:	5888 V, U/N: F1002, hydraulic modification 2, A_{ot}: 49.13, A_{ft}: 62.3, V_o (1500 K): 167.0, V_f (1500 K): 75.7
Description:	5U baffled (13x3 wide-base, fuel-cooled); 0.228-inch-diameter fuel doublets at 40 degrees, 0.185-inch-diameter LOX triplets at 40 degrees; nine LOX triplets and 128 LOX showerheads in the outer ring and next to the radial baffles have been plugged; 0.1285-inch-diameter film and 0.076-inch-diameter body coolant orifices, yielding 10.8 percent wall coolant; rotated baffles and ASME orifices in all but the outer ring
Objective:	Evaluation of the effect of the plugged LOX orifices on stability
Test Results:	In four tests, four bomb disturbances damped in 12, 11, 65, and 440 milliseconds with one thrust chamber erosion occurring at the 6:30 location; the mode of instability was similar to that of the standard PFRT injector: 500-cps oscillations coupled with resuring
Tests:	284 and 285 (2A-1) 9-2-64
Injector Type:	5885 P3, U/N: 092, (084D type), A_{ot}: 61.8, A_{ft}: 85.1, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter fuel doublets at 30 degrees, (outer ring is 0.228-inch-diameter at 40 degrees and is orificed to 70 degrees normal flow in the axial feed holes), 0.242-inch-diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch-diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch-diameter at 40 degrees), 302 LOX splitters, 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2 percent wall coolant
Objective:	Investigation of performance, stability and burning characteristics of this injector
Test Results:	Four bomb disturbances damped in 12, 10, 10, and 168 milliseconds; in the first test an erroneous RCC was incurred and hardware inspection after test 285 revealed four tube splits and eight transverse chamber cracks

TABLE 1

(Continued)

Frequency Analysis:	In test 285, the mode was similar to that of a PFRT injector; 500-cps oscillations coupled with resuring; there appeared to be no significant difference during the first few milliseconds between the single-cycle instabilities and the 168-millisecond instability
Tests:	286, (2A-1) 9-4-64
Injector Type:	5869 R3, U/N: X035, A_{ot}: 41.9, A_{ft}: 86.2, V_0 (1500 K): 195.0, V_f (1500 K): 55.0
Description:	5U baffled (3-compartment, uncooled), 0.281-inch-diameter fuel doublets at 30 degrees, outer fuel ring consists of 0.228-inch-diameter doublets at 40 degrees, 0.159-inch-diameter LOX triplets at 40 degrees, no film or body coolant orifices, 237 LOX splitters, 4.4 percent wall coolant
Objective:	Investigation of the effect of the hydraulic modifications on the stability of this injector
Test Results:	Bomb-induced instability, which did not damp, but programmed cutoff occurred before initiation by the RCC device; the inconel-X O-ring was broken by the instability
Frequency Analysis:	The instability contained characteristics of both the 500-cps mode and a higher frequency tangential mode exhibited previously on flat-face injectors; the chamber oscillations were steep fronted and high-amplitude, but the feed system indicated 500-cps oscillations
Tests:	287 through 290 (2A-1) 9-8-64 (2) 9-9-64
Injector Type:	5889 P3, U/N; X054, A_{ot}: 59.80, A_{ft}: 83.60, V_0 (1500 K): 136.5, V_f (1500 K): 56.70
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter doublets at 30 degrees (outer ring consists of 0.228-inch-diameter doublets at 29 degrees along radial baffles canted 8 degrees away from radial baffles, 0.209-inch-diameter LOX doublets at 40 degrees in outer ring, 0.182-inch-diameter LOX doublets in -9, -11, -31, and -33 rings, 0.242-inch-diameter LOX doublets at 40 degrees 47 minutes along radial baffles canted 8 degrees away from the baffles, 0.242-inch-diameter LOX doublets at 40 degrees elsewhere, 40 baffle dams 302 splitters (spoon-type) outer ring orificed from 70 percent flow, no film or body coolant holes, 3.2 percent wall coolant
Objective:	Evaluation of the effect on stability of minimizing the amount of fuel and oxidizer on baffle surfaces
Test Results:	In four tests with tube wall thrust chamber 20-4, two bomb disturbances damped in 27 and 55 milliseconds with five tube splits occurring during the fourth test; in both tests, two resurges occurred along with 200 to 500 cps oscillations

TABLE 1

(Continued)

Tests:	291 (2A-1) 9-10-64
Injector Type:	5830 XX, U/N: X007A, A_{ot}: 53.3, A_{ft}: 63.33, V_o (1500 K): 153.5, V_f (1500 K): 74.8
Description:	5U baffled (13x3 wide-base, fuel-cooled); 0.228-inch-diameter fuel doublets at 40 degrees matched to inboard 0.185-inch-diameter LOX triplets at 40 degrees, 184 film coolant holes of 0.154-inch-diameter, 100 0.076-inch-diameter body coolant holes, 32 dams in outer fuel ring, modification 2 except there are no flame suppressors in the outer two rings, ASME orifices in all but the outer two rings, 14.1 percent wall coolant
Objective:	Investigation of temperature in the O-ring area during a resurging instability
Test Results:	13.5-grain bomb induced resuring instability which persisted for 175 milliseconds and caused bending of the radial baffles
Tests:	292 through 296 (2A-1) 9-11-64 (1), 9-12-64 (4)
Injector Type:	5885 S3, U/N: 092, (084E type), A_{ot}: 61.8, A_{ft}: 85.1, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter fuel doublets at 30 degrees, (outer ring is 0.288-inch-diameter at 40 degrees and is orificed to 70 percent normal flow in the axial feed holes), 0.242-inch-diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch-diameter at 28 degrees 12 minutes half angle, outer ring and rings next to the circumferential baffles are 0.209-inch-diameter at 40 degrees), 302 LOX splitters (spoon-type), 32 dams in the outer and 8 dams in the inner circumferential baffle, no film or body coolant orifices, 3.2 percent wall coolant; baffle land gap not sealed, rotated bomb bosses
Objective:	Investigation of performance, stability and burning characteristics of this injector
Test Results:	In five tests with tubular wall thrust chamber 20-30, four bomb disturbances damped in 17, 8, 10, and 28 milliseconds; after the final test, tube failures were observed in compartments 1 and 5
Frequency Analysis:	A bomb disturbance triangulated to the new bomb boss at the 12.45 o'clock location; in the final test, the bomb produced a relatively low-amplitude disturbance, which was followed 7 milliseconds later by a resurge, which initiated in another area of the chamber, and induced 500-cps oscillations

TABLE

(Continued)

Tests:	297 through 300 (2A-1) 9-14-64 (1) 9-15-64 (3)
Injector Type:	5890 V, U/N: F1002, A_{ot}: 49.3, A_{ft}: 62.3, V_o (1500 K): 165.5, V_f (1500 K): 75.7
Description:	5U baffled (13x3 wide-base, fuel-cooled); basically a PFRT type, 0.228-inch-diameter fuel doublets at 40 degrees included angle; 0.185-inch-diameter LOX triplets at 40 degrees included angle, 128 LOX showerheads adjacent to the radial baffles plugged, 9 LOX triplets in the outer ring plugged, 112 orifices adjacent to the radial baffles enlarged to 0.1935-inch-diameter, 184 film coolant orifices 0.1285-inch-diameter, 100 body coolants 0.076-inch-diameter, ASME orifices in all but the outer ring, hydraulic modification 2, 10.8 percent wall coolant
Objective:	To evaluate the effect of the canted doublets in conjunction with triplets on dynamic stability
Test Results:	In four tests with a solid-wall thrust chamber, four bomb disturbances damped in 7, 13, 12, and 7 milliseconds; in all instances a high-amplitude chamber disturbance was observed (approximately 3500 psi) and damping in the chamber appeared to be periodic
Tests:	301 and 302 (2A-1) 9-16-64
Injector Type:	5885 S3, U/N: 092, (084E type), A_{ot}: 61.8, A_{ft}: 85.0, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled) 0.281-inch-diameter fuel doublets at 30 degrees included angle except for outer ring which consists of 0.228-inch-diameter fuel doublets at 40 degrees included angle and is orificed to 70 percent normal flow in the axial feed holes; 0.242-inch-diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to radial to 0.250-inch-diameter at 28 degrees 12 minutes half angle, outer ring and rings next to circumferential baffles are 0.209-inch-diameter at 40 degrees) 286 LOX splitters, 32 dams in outer, 8 dams in inner circumferential baffle, baffle-to-land gap not sealed, no film or body coolant orifices, 3.2 percent wall coolant
Objective:	Investigation of dynamic stability of 084E-type injector
Test Results:	Two bomb-induced disturbances damped in 57 and 10 milliseconds; high amplitude chamber disturbance observed during both instabilities
Frequency Analysis:	Both instabilities were the resurging type coupled with 500-cps oscillations, which is similar to that of the PFRT injector

TABLE 1

(Continued)

Tests:	303 through 306 (2A-1) 9-17-64
Injector Type:	5833 U3, U/N: 082, A_{ot}: 49.2, A_{ft}: 85.0, V_o (1500 K): 166, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter fuel doublets at 30 degrees included angle (outer ring 0.228-inch-diameter at 40 degrees), 0.209-inch-diameter LOX doublets at 56 degrees 24 minutes included angle (adjacent to radial baffles 0.209-inch-diameter at 40 degrees) 16 dams outer and 8 dams inner circumferential baffle, 164 fuel ring groove, dams, baffle-to-land gap not sealed, 4.6 percent wall coolant
Objectives:	Investigate effect of baffle-to-land gap on 500-cps buzz
Test Results:	In four tests with solid-wall thrust chamber, two bomb-initiated disturbances (tests 305 and 306) were damped in 5 and 6 milliseconds, however, neither disturbance registered over 282 g on the RCC's
Frequency Analysis:	The two disturbances damed without resuring; low amplitude 500 to 600 cps observed in fuel system and in chamber pressure of "P_c 0.8" level
Tests:	307 through 311 (2A-1)
Injector Type:	5891 P3, U/N: X054, A_{ot}: 60.15, A_{ft}: 83.60, V_o (1500 K): 136, V_f (1500 K): 56.70
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter fuel doublets at 30 degree included angle (outer ring 0.228-inch-diameter at 40 degrees, adjacent to radial baffles in -13 and -35 rings; 0.199-inch-diameter at 30 degrees, remaining fuel doublets along radials 0.281-inch-diameter at 30 degrees included angle canted 7 degrees away from baffle); 0.242-inch-diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to the radial to 0.250-inch-diameter at 28 degrees 12 minutes, the other orifice is 0.242-inch-diameter at 12 degrees 35 minutes; the -9, -11, -31, -33 LOX rings are 0.182-inch-diameter at 40 degrees); 302 LOX spooned splitters, 40 baffle dams, outer fuel ring orificed for 70 percent normal flow, 3.2 percent wall coolant
Objectives:	Investigation of performance, stability and burning qualities of this injector
Test Results:	In five tests in a tube wall thrust chamber, six bonb-induced disturbances damped in a single cycle except the first on test 311 (72 milliseconds), which was a resurging type instability coupled with 500-cps oscillations

[redacted]

TABLE 1

(Continued)

Tests:	312 (2A-1) 9-19-64
Injector Type:	5882 N3, U/N: X055, A_{ot}: 49.2, A_{ft}: 85.1, V_o (1500 K): 166.1, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled); 0.281-inch-diameter fuel doublets at 30 degrees included angle (outer ring 0.228-inch-diameter fuel doublets at 40 degrees), 0.209-inch-diameter LOX doublets at 40 degrees 12 minutes half angle (-9 ring has 0.209-inch-diameter LOX doublets at 40 degrees, LOX doublets next to radial baffles except adjacent to circumferential baffles 0.209-inch-diameter at 56 degrees 24 minutes included angle, canted away from baffle); 314 LOX splitters, 164 fuel ring groove dams, deep fuel ring grooves, 24 baffle dams, 3.2 percent wall coolant, baffle land gap not sealed
Objective:	Further investigation of the effect of the baffle land gap on the 500-cps buzzing
Test Results:	No bomb or self-induced instabilities on this tube wall thrust chamber test; steady-state RCC level was 20 g
Frequency Analysis:	Low-amplitude (50 to 100 psi) cps in fuel system and chamber pressure
Tests:	313 (2A-1) 9-21-64
Injector Type:	5885 S3, U/N: 092, (084E type), A_{ot}: 61.8, A_{ft}: 85.1, V_o (1500 K): 132.2, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled) 0.281-inch-diameter fuel doublets at 30 degrees included angle except for outer ring which consists of 0.228-inch-diameter fuel doublets at 40 degrees included angle and is orificed to 70 percent normal flow in the axial feed holes; 0.242-inch-diameter LOX doublets at 40 degrees (fans along radial baffles are canted by drilling the LOX orifices next to radial to 0.250-inch-diameter at 28 degrees 12 minutes half angle, outer ring and rings next to circumferential baffles are 0.209-inch-diameter at 40 degrees), 286 LOX splitters, baffle to land gap not sealed, 3.2 percent wall coolant
Objective:	Investigate dynamic stability of 084E-type injector
Results:	13.5-grain bomb induced resuring instability, which persisted for 385 milliseconds and caused bending of radial baffles; there were lower O-ring and backup ring failures
Frequency Analysis:	The instability consisted of 500 and higher frequency oscillations accompanied by a few high-amplitude resurges

[redacted]

TABLE 1

(Continued)

Tests:	314 through 316 (2A-1) 9-22-64
Injector Type:	5892 V3, U/N: X037, A_{ot}: 44.8, A_{ft}: 46.1, V_o (1500 K): 182.0, V_f (1500 K): 102.8
Description:	5U baffled (13x3 wide-base, bipropellant-cooled), 0.199-inch-diameter fuel doublets at 30 degrees included angle (fuel doublets adjacent to baffles are 0.199-inch-diameter at 30 degrees included angle and canted approximately 8 degrees away from baffle, outer fuel ring consists of 0.199-inch-diameter orifices at 40 degrees included angle); 0.159-inch-diameter LOX triplets at 40 degrees included angle (LOX doublets along baffle 0.1935-inch-diameter at 40 degrees 47 minutes included angle and canted approximately 8 degrees away from baffle), deep fuel grooves, shallow LOX grooves, 205 LOX splitters, 7.1 percent wall coolant
Objectives:	Investigate the operating characteristic of the tribaffle, bipropellant-cooled injector
Results:	In three tests with a solid-wall thrust chamber, one 13.5-grain bomb induced resurging instability which persisted for 700 milliseconds
Frequency Analysis:	Resurging instability in chamber, 1300 to 1500 cps between surges; the feed systems had a 500-cps mode for entire instability
Tests:	317 (2A-1) 9-22-64
Injector Type:	5893 V, U/N: X012, A_{ot}: 45.2, A_{ft}: 27.0, V_o (1500 K): 181, V_f (1500 K): 176
Description:	Baffled (11x3 uncooled, 1/2 inch except for outer radials which are 7/8 inch), 0.125-inch-diameter fuel doublets impinging subface at 34 degrees (outer ring is 0.125-inch-diameter showerhead canted 20 degrees toward the chamber wall), 0.0937-inch-diameter LOX doublets impinging subface at 34 degrees, 96 body coolant holes, spray fans rotated such that unlike impingement of fan tips does not occur, 16.75 percent wall coolant
Objectives:	Investigate damping characteristics of rotated fan concept
Results:	13.5-grain bomb induced resurging instability which continued for 700 milliseconds, causing bending and eroding of baffles
Frequency Analysis:	The oscillations were of high frequency but comparatively low amplitude in all parameters except chamber pressure taps at injector face where high amplitudes (5000 psi) were recorded

TABLE 1

(Continued)

Tests:	318 and 319 (2A-1) 9-23-64
Injector Type:	5894 R3, U/N: X035, A_{ot}: 42.3, A_{ft}: 87.0, V_o (1500 K): 193, V_f (1500 K): 55.0
Description:	Standard 5U baffled (3x3 wide-base), 0.281-inch-diameter fuel doublets at 30 degrees included angle (outer fuel ring 0.228-inch-diameter at 40 degrees included angle), 0.159-inch-diameter LOX triplets at 40 degrees included angle, 237 LOX splitters, baffle tips cut back two rings, 4.7 percent wall coolant
Objectives:	Investigate damping characteristics of shortened radial baffle
Results:	Two solid-wall thrust chamber tests; 13.5-grain bomb induced an instability which continued for 500 milliseconds; posttest inspection revealed a LOX leak at weld near 180 degrees location
Frequency Analysis:	500 cps in all parameters with high-amplitude spikes (7500 psi in chamber pressure)
Tests:	320 and 321 (2A-1) 9-24-64, 9-25-64
Injector Type:	5881 M3, U/N: 084, (084C Type), A_{ot}: 61.4, A_{ft}: 85.1, V_o (1500 K): 133.0, V_f (1500 K): 55.7
Description:	Modified 5U baffled (13x3 wide-base, fuel-cooled), 0.281-inch-diameter fuel doublets at 30 degrees included angle (outer fuel ring 0.228-inch-diameter at 40 degrees included angle), 0.242-inch-diameter LOX doublets (doublets adjacent to radial baffles in LOX rings -53, -49, -45, -41, -37, -27, -23, -19, and -15 have 0.242-inch-diameter at 48 degrees 12 minutes included angle, all LOX doublet next to radial baffles are 0.242-inch-diameters at 48 degrees 12 minutes included angle and canted 40 degrees from baffle), 40 baffle dams, 314 LOX splitters, outer fuel ring orificed for 70 percent normal flow, 3.2 percent wall coolant
Objectives:	To evaluate performance level of test stand 2A-1 as opposed to test stand 1B
Results:	Two tube wall thrust chamber tests with two self-initiated instabilities which damped in 8 and 155 milliseconds; second instability initiated in the area of the No. 2 inlet; shifted splitters were noted after each test
Tests:	322 through 325 (2A-1) 9-26-64
Injector Type:	5895 V, U/N: F1002, A_{ot}: 49.85, A_{ft}: 62.3, V_o (1500 K): 163.5, V_f (1500 K): 75.7
Description:	5U baffled (13x3 wide-base, fuel-cooled) 0.228-inch-diameter fuel doublets at 40 degrees included angle, 0.185-inch-diameter LOX triplets at 40 degrees included angle, 128 showerheads next to radial baffles plugged, orifice adjacent to radial

TABLE

(Concluded)

Description: (Continued)	of remaining LOX doublets drilled to 0.209-inch-diameter at 28 degrees 12 minutes half angle, except in outer LOX ring, 100 body coolants at 0.076 degree, ASME orifices except in outer ring, hydraulic modification 2; 10.8 percent wall coolant
Objectives:	Investigate effect of canted LOX fans on dynamic stability
Results:	Three bomb induced instabilities damped in 13, 20, and 13 milliseconds (1 cycle); comparatively high amplitude (4000 psi) disturbances were noted in chamber pressure

data had indicated the LOX flowmeter to be in error. The six tests were successful, and the data indicated the flowmeter to be in error by approximately 3 percent. (This study is discussed in detail in Volume 2, Book 3).

EVOLUTION OF THE FRT INJECTOR

The FRT injector evolved from the Type 5867 J3 injector (Fig. 18 and 19). This injector type has a 5U orifice pattern with 0.281-inch-diameter fuel doublet orifices impinging at 30 degrees included angle, except in the outer ring where they impinge at 40 degrees and the orifice diameter is 0.228 inch. The outer fuel ring is also restricted to approximately 50 percent of its normal flow. The LOX side has 0.242-inch-diameter doublet orifices impinging at 40 degrees, except in the outer ring and adjacent to the baffles where they are 0.209-inch in diameter, impinging at 40 degrees. There are 314 LOX splitters in the axial feed passages. The injector is divided into 13 compartments by 3-inch-high, wide-base, fuel cooled baffles. Forty dams in the circumferential baffles prevent the occurrence of an annular mode. The outer radial baffles are rotated 12.5 degrees with respect to the inner radials.

Four series of tests were conducted on injector type 5867 J3 to investigate the repeatability of results with different injector units. The tests were conducted on injectors U/N X056 and 092. The results from the two injectors were similar. The average damp time with U/N X056 was 25 milliseconds, with extremes of 73 and 8 milliseconds. Damp times in two stability tests on U/N 092 were 58 and 37 milliseconds.

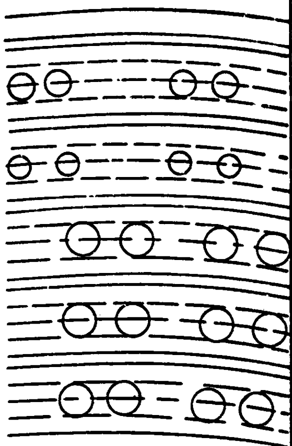
Six of the 10 tests on injector U/N X056 showed indications of 400-cps buzzing at amplitudes from 50 to 400 psi peak to peak. This buzz is similar to the 500-cps buzz in that the sinusoidal oscillations grow linearly in

[redacted]

INJECTOR DESCRIPTION

UNIT 092 & X056, TYPE 5867 J3, S/N ____

ORIFICE PATTERN

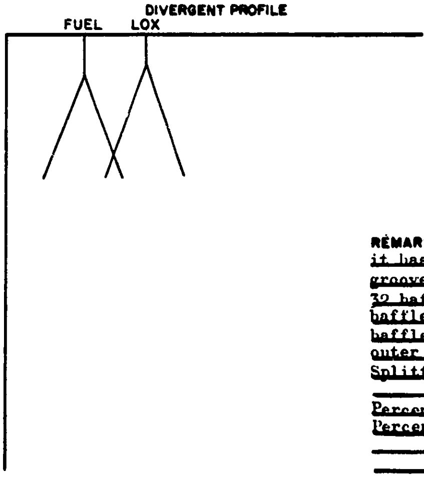


NO.	D	φ	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
-55	35.626	0.281	88/96	0.428	15°	1.17	0.799	0.254
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.238
Except LOX holes (0.209) next to all baffles								
-51	33.386	0.281	80/88	0.428	15°	1.22	0.744	0.254

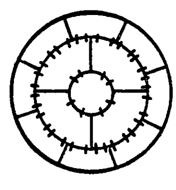
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	58.8
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
	55.6	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES

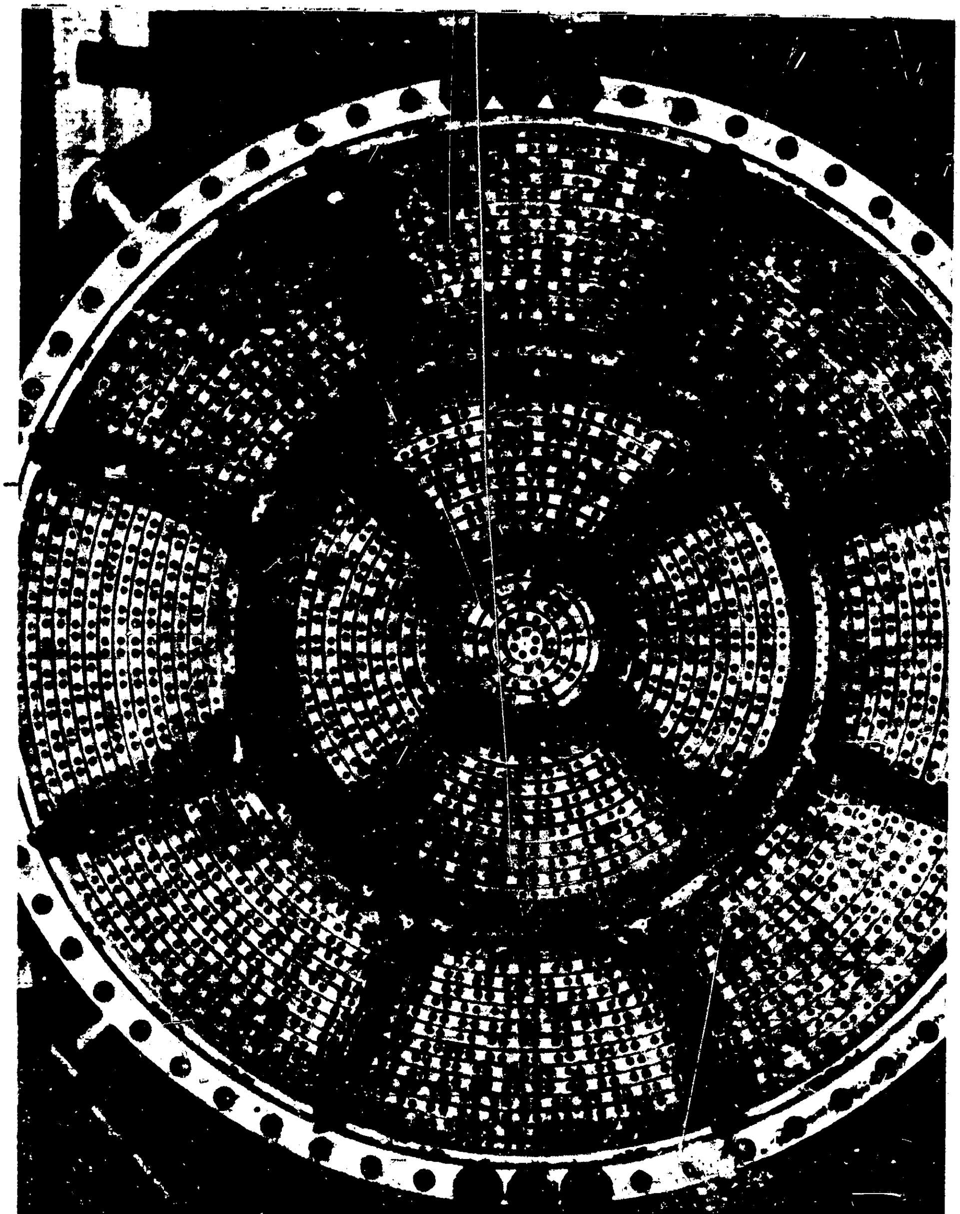


REMARKS: The injector is like unit 081 except it has rotated baffles, baffle dams, deep LOX grooves, and fuel port isolation tabs. There are 32 baffle dams in the outer circumferential baffle and 8 dams in the inner circumferential baffle. There are 314 LOX splitters. The outer ring is orificed for 50-percent flow. Splitters placed as in Unit 081, Type 5867 A3.

Percent film coolant = 4.6
Percent excess fuel on wall = 2.2

Figure 18. Injector U/N 092 and X056, Type 5867J

[redacted]



1DB45-5/20/64-C1Q

Figure 19. Injector U/N 092, Type 5867J3, First FRT Injector Type

time and both appear to be a transverse mode (Fig. 20 and 21). They differ in phase relationship. The phase relationship of the 500-cps mode is such that a nodal line can be drawn connecting the propellant inlets; the nodal line of the 400-cps buzz is perpendicular to this line.

The type 5867 J3 injector was modified to improve mixture ratio distribution in the outer combustion zone. This was accomplished by increasing the fuel flow in the outer ring from 50 to 70 percent (type 5867 M3). The average damp time for four bomb tests was 33 milliseconds. The injector again showed indications of 400-cps buzzing at amplitudes from 50 to 400 psi peak to peak.

The LOX orifices adjacent to the radial baffles were then enlarged to 0.242 inch in diameter and canted away from the baffles by drilling the orifice nearest the baffle at a 28-degree 12-minute half angle, and its impinging orifice at a 20-degree half angle (Fig. 22). The injector was redesignated 5881 M3.

The injector demonstrated good stability, but self-triggered instability in two tests. The self-triggered instability damped in 8 and 155 milliseconds.

A type 5881 M3 injector was modified by canting the fuel fans along the radial baffles to match the previously canted LOX fans, but it did not appear that canting both LOX and fuel fans was as effective as canting the LOX fans only.

The type 5881 M3 injector was further modified by enlarging the 0.242-inch-diameter by 28.2-degree LOX orifices adjacent to the radial baffles to 0.250 inch in diameter to prevent LOX from impinging on the baffle (due

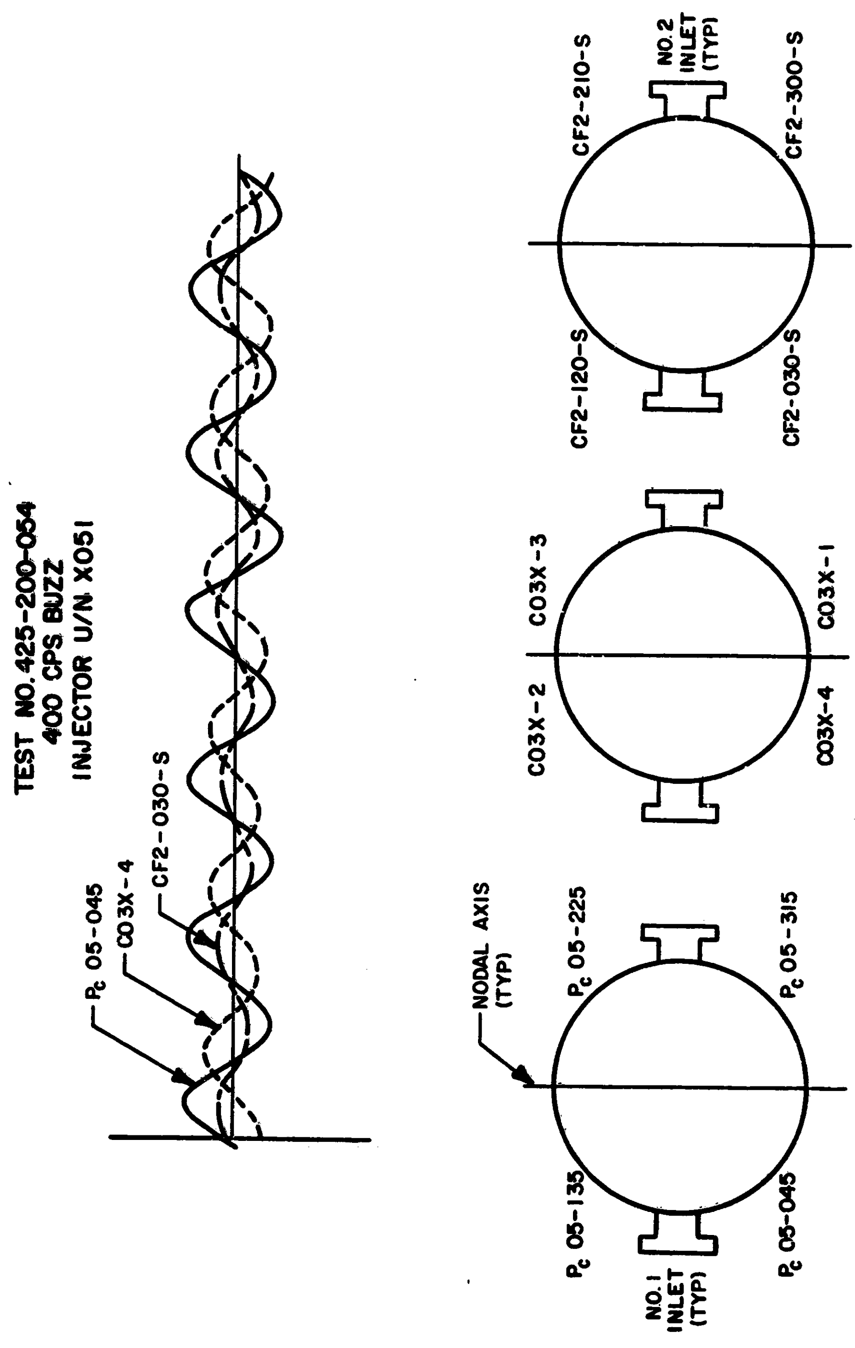


Figure 20. Phase Relationship of 400-cps Buzz Instability

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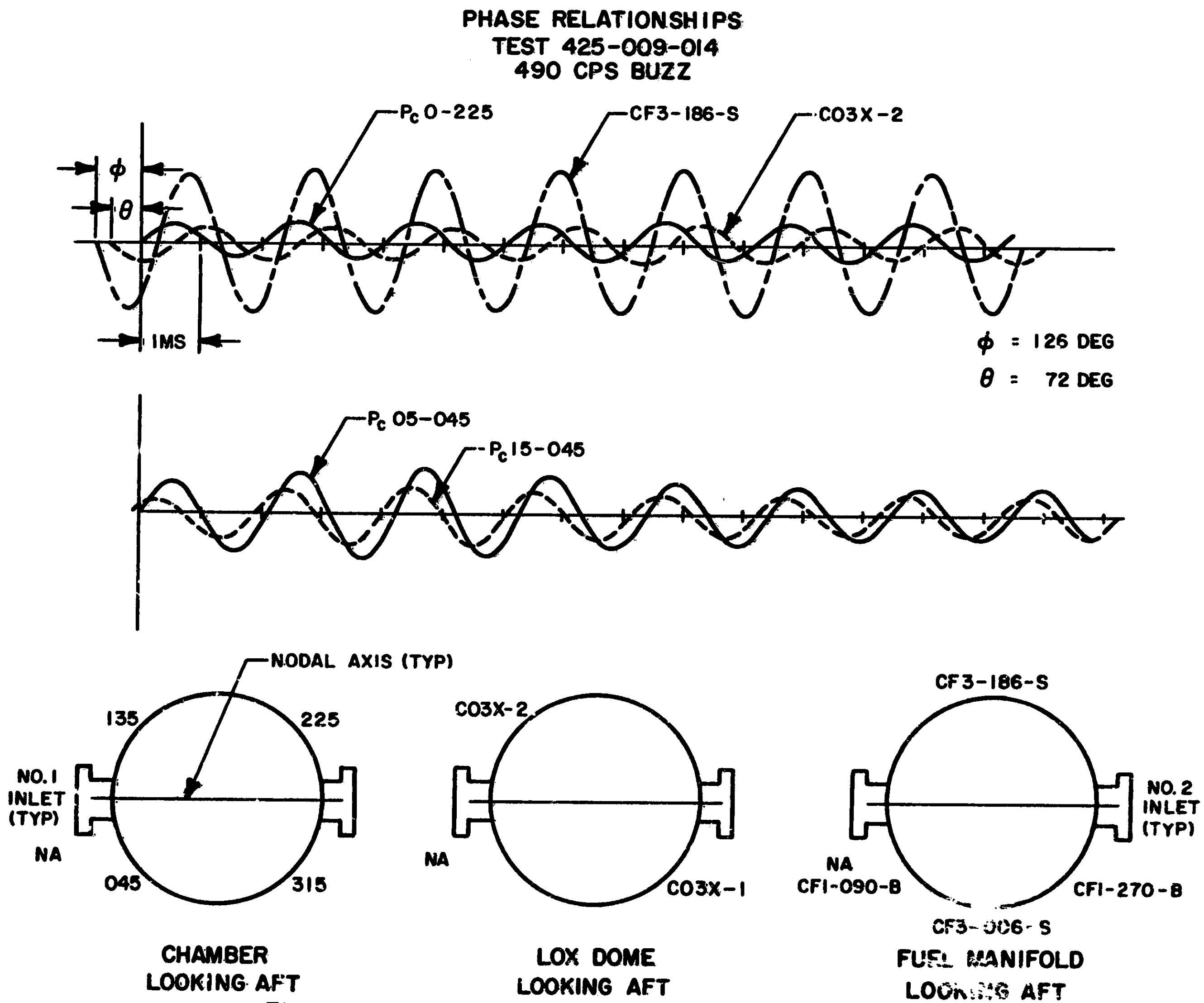

Figure 21. Phase Relationship of 500-cps Instability

[redacted]

[redacted]

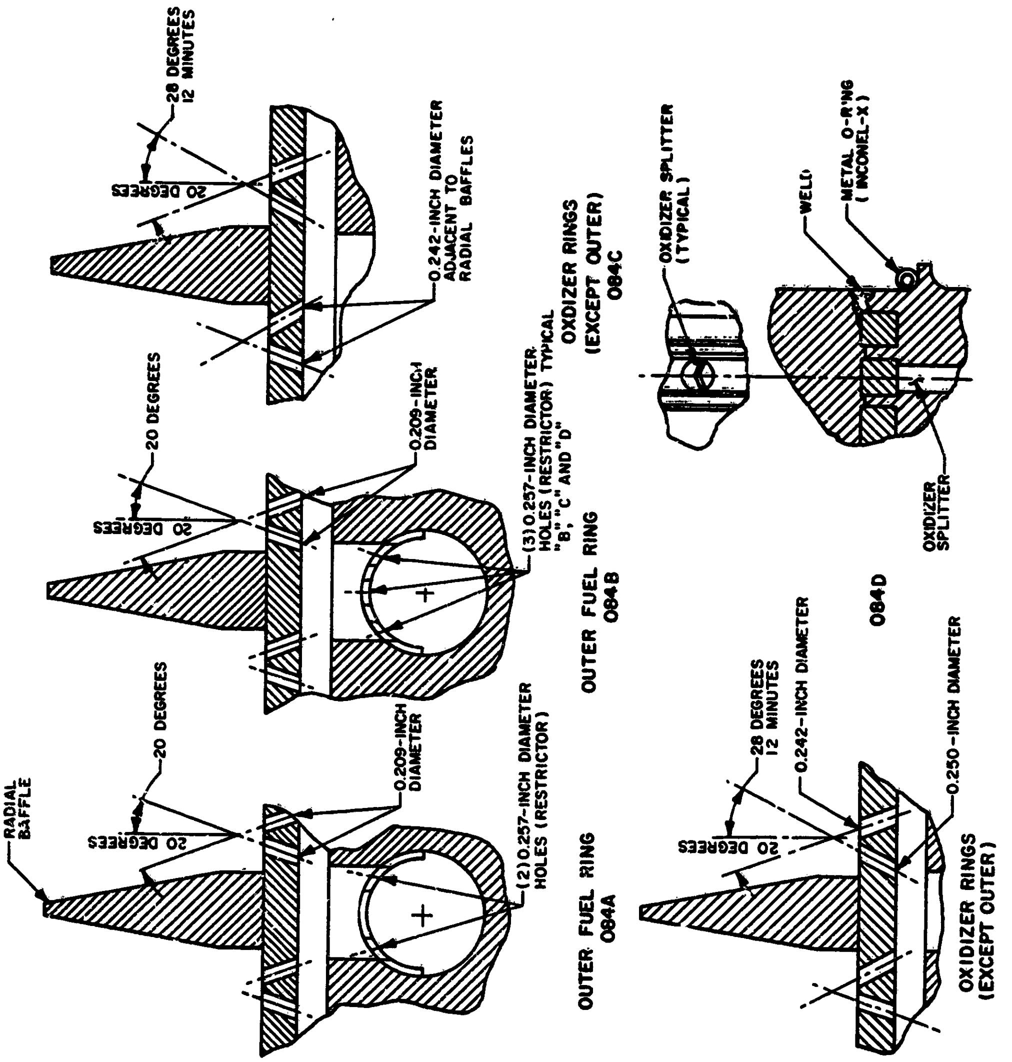

Figure 22. Evolution of Injector 084

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[redacted]

to any misalignment of the doublets). In addition, the LOX splitters were crimped to avoid interference with the LOX orifices (Fig. 23). The injector type was designated 5885 P3.

Twelve stability evaluation tests were conducted on this injector. Nine bomb-induced instabilities damped in less than 14 milliseconds; two damped in 54 and 168 milliseconds.

It appeared that the stability and performance of the FRT injector had been improved with no loss in compatibility. However, a new problem of an increased frequency of self-triggering was encountered. Repeated shifting of 16 oxidizer splitters which divide the oxidizer doublets adjacent to the eight radial baffles in the outer ring was observed on U/N 092 (Type 5881 M3) and 099 (Type 5885 P3) injectors. Because this splitter movement obstructs the entrance to the oxidizer orifices the splitters have been removed from the present FRT injector (Type 5885 S3). The new configuration also includes a new bomb boss design which does not impede flow through the adjacent fuel orifices and the land-to-baffle gaps are open to permit inter-compartment venting.

Eight tests were conducted with the Type 5883 S3 injector on the EFL component test stand 2A-1. Six bomb-induced instabilities were damped in less than 100 milliseconds, with an average damp time of approximately 21 milliseconds.

A total duration of 1254 seconds was accumulated during engine testing on the Type 5883 S3 injector on three injector units (U/N 085, 086, and 098). Engine 011-2 was bombed on one occasion, and the disturbance was damped in 89 milliseconds. There were no instances of self-induced mainstage "popping".

[redacted]

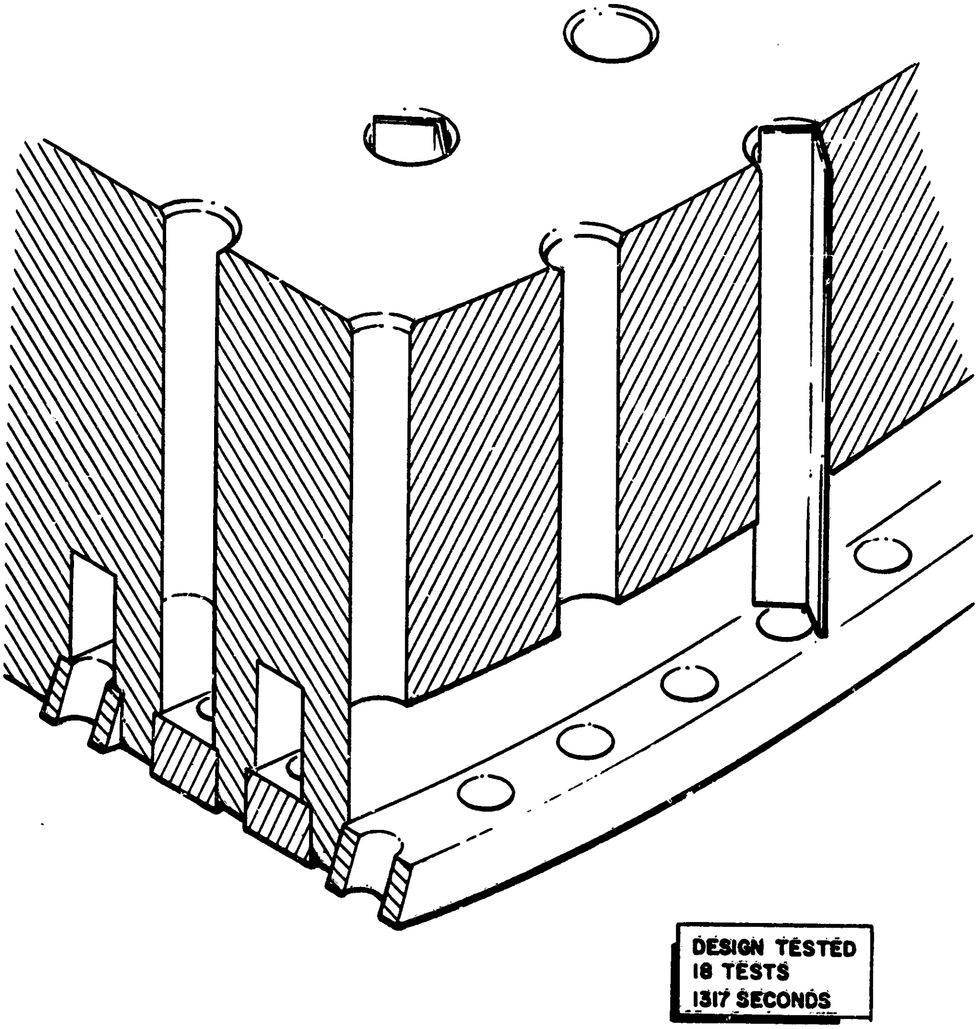


Figure 23. Crimped LOX Splitters

A significant increase in engine performance was realized in converting from the U/N 084B to theU/N 084C injector. After 2593 seconds of testing, the U/N 084C (Type 5881 M3) injector demonstrated a favorable average engine specific impulse of 262.3 seconds as compared to the previous U/N 084B average specific impulse of 259.6 seconds. Increased canting of the oxidizer fans improved performance slightly on the U/N 084D (Type 5885 P3) injector, with the average specific impulse being 262.5 seconds after more than 1300 seconds of testing. No further improvement was obtained with the U/N 084E (Type 5885 S3) injector, however, the structural integrity of the injector was significantly improved.

CONCEPTS EVOLVED FROM FRT TESTING

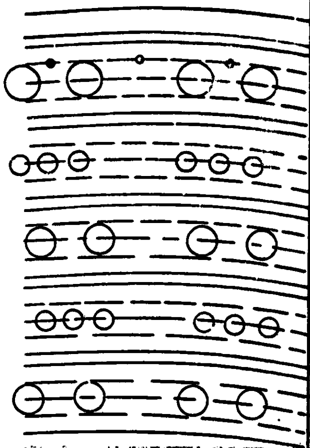
The concept of minimizing the propellants on baffle surfaces by canting the fans was further evaluated on the Block 1 injector U/N F1002 and tribaffled injector U/N X037. The outstandingly strong damping characteristics of injector U/N F1002 demonstrated the high sensitivity of the area near the baffle surfaces with respect to dynamic stability. The damping characteristics of injector U/N X037 appeared to be unchanged. (i.e., the instability was not damped.)

Injector U/N F1002 (Fig. 24) had a 5U baffled orifice pattern, 0.228-inch-diameter fuel doublets impinging at 40 degrees, and 0.185-inch LOX triplets impinging at 40 degrees. All elements except those in the outer ring are A.S.M.E. orifices. The injector has 0.128-inch-diameter film and 0.076-inch-diameter body coolant orifices. Total wall coolant is 10.8 percent. The baffle configuration is like that of the FRT injector, and it has hydraulic modification No. 2. (Ref. Vol. 1 Book 4, Page 41)

INJECTOR DESCRIPTION

UNIT F1002, TYPE 5895V, S/N

ORIFICE PATTERN

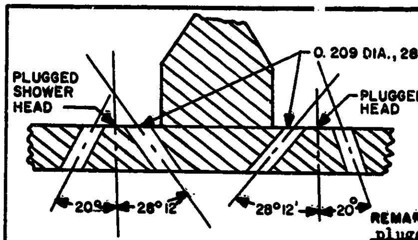


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
	37.961	0.1285	184/200	-	-	-	-	-
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.185	87/104	0.416	20°	1.11	0.571	0.317
Shower heads adjacent to radials are plugged.								
-55	35.620	0.228	88/96	0.416	20°	1.17	0.571	0.258
-53	34.506	0.185	88/96	0.416	20°	1.13	0.571	0.317
Except LOX orifice next to radial is 209-inch diameter, 28° 12'.								
-51	33.386	0.228	80/44	0.416	20°	1.17	0.571	0.258

PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	62.3	49.85
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.916	
Inj. Velocity(1500K)	75.7	163.5

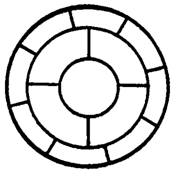
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



LOX GROUPS NEXT TO RADIALS (EXCLUDING OUTER LOX RING)

BAFFLES



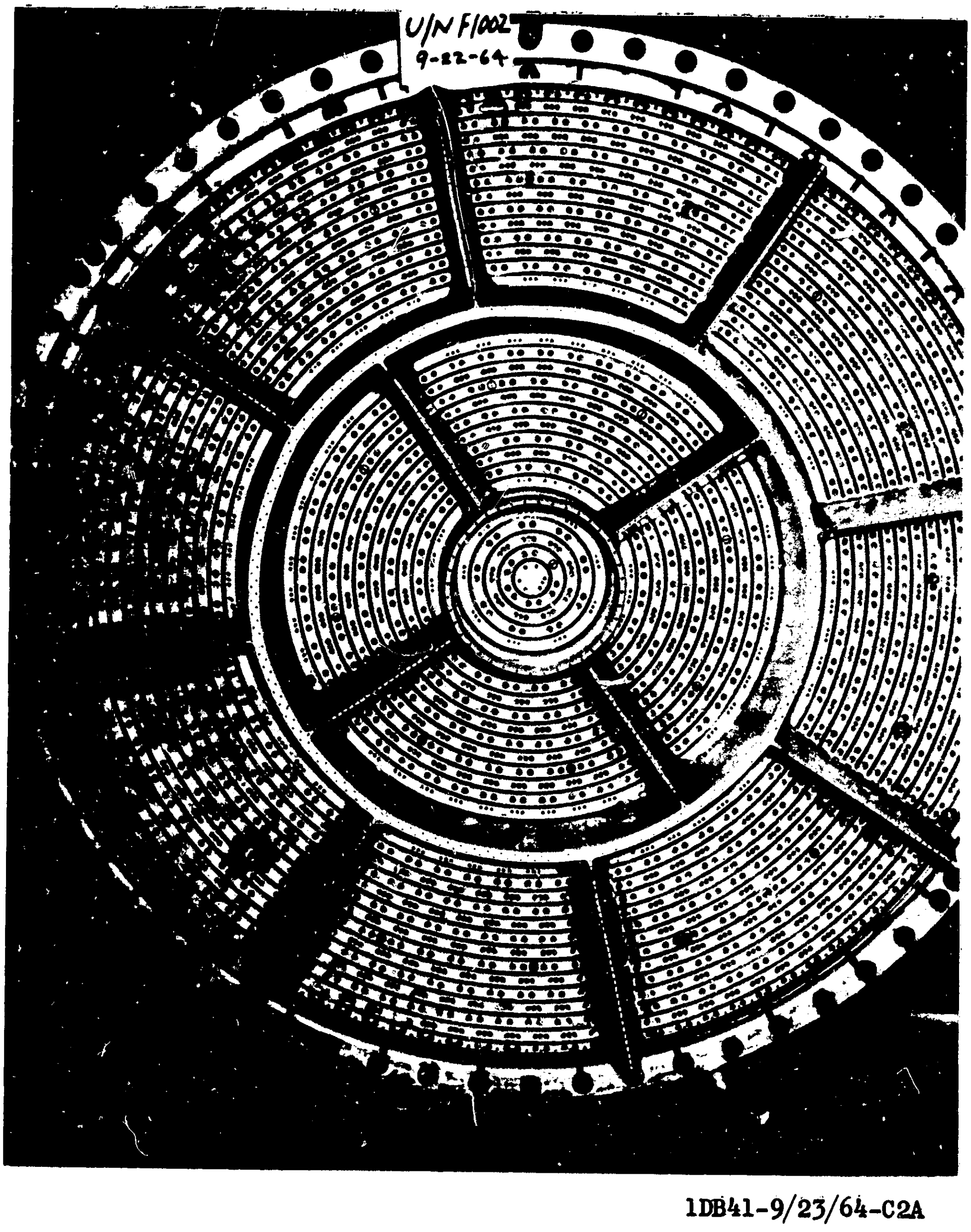
REMARKS: Nine LOX triplets in outer ring are plugged; 128 LOX shower heads adjacent to radial baffles are plugged; 112 orifices reamed to 0.209-inch diameter, 28° 12' as shown at left, excluding outer LOX ring; 100 body coolants remain at 0.076 inch diameter; injector has A.S.M.E. orifices except in outer ring; hydraulic modification No. 2

Percent film coolant = 10.8%

Percent excess fuel = 6.5%

Figure 24. Injector U/N F1002, Type 5895V, Modified PFRT Injector

[redacted]



1DB41-9/23/64-C2A

Figure 24. (Concluded)

[redacted]

[redacted]

The stability of the Block 1 injector was greatly improved by plugging the LOX showerhead and canting the remaining doublets away from the radial baffles. Characteristic damping times before canting were approximately 60 milliseconds; with canting they were less than 13 milliseconds.

Both LOX and fuel fans were canted away from the tribaffled injector U/N X037. The concept did not appear to be effective, as bomb-induced instabilities persisted until chamber pressure decay.

HYDRAULIC MODIFICATIONS

Injector U/N X035 (Fig. 25 through 27), which had previously demonstrated dynamic stability by damping three bomb disturbances (each in one cycle) was tested twice without the hydraulic modifications (Fig. 28). In both cases, a 500-cps, high-amplitude, transverse instability persisted until chamber pressure decay. Two attempts to repeat the first series, with hydraulic modifications, were made. In test 267, with the hydraulic modifications replaced, and in test 280 with LOX splitters only, a bomb-induced instability persisted until chamber pressure decay. A possible explanation of the inconsistency was the variation in the installation of the LOX splitters.

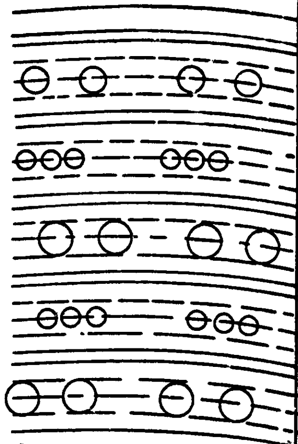
500-cps BUZZ EVALUATION

The investigation of the 500-cps buzz instabilities with the injector U/N 082 (Fig. 29 and 30) was continued. The fuel system of this type injector is similar to the FRT injector, except that the outer fuel ring is not restricted. The LOX system has 0.209-inch-diameter doublet orifices impinging at 56.4 degrees included angle, and the orifices adjacent to the radial baffles are canted at 28.2 and 20 degrees. The radial baffles are in-line.

[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN



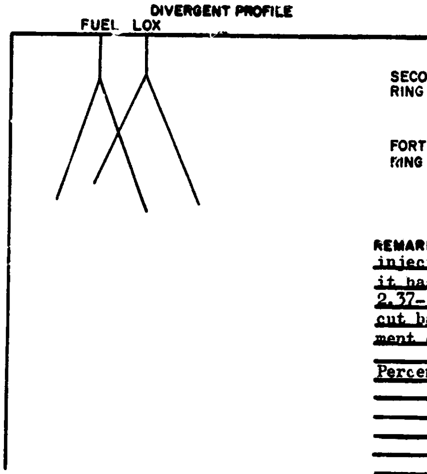
UNIT X035, TYPE 5894 R3, S/N

NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-69	37.776	0.228	100/100	0.415	20°	1.19	0.571	0.258
-67	36.746	0.159	100/100	0.416	20°	1.15	0.571	0.353
-65	35.626	0.281	86/94	0.428	15°	1.19	0.799	0.275
-63	34.506	0.159	84/94	0.416	20°	1.16	0.511	0.353
-61	33.386	0.281	80/87	0.428	15°	1.21	0.799	0.275

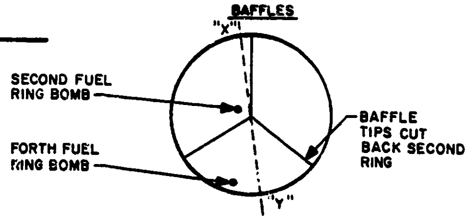
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	87.0	42.3
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
	55	193

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	3
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	None
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



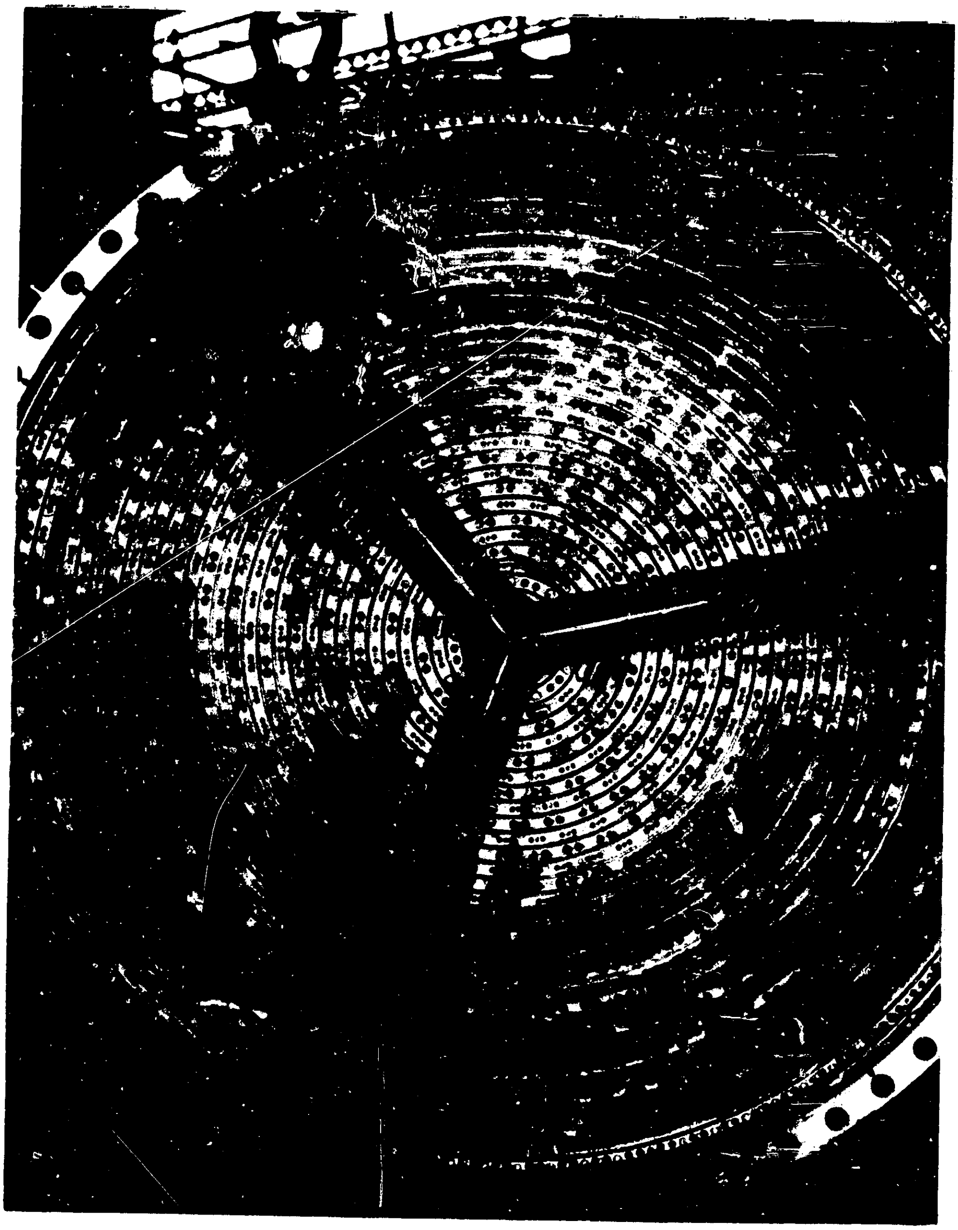
BAFFLES



REMARKS: Standard 5U flat-face pattern with injectors like U/N X035, Type 5869-03 except that it has no hydraulic modifications other than 2.37-inch LOX splitter. Also, the baffles were cut back two rings, and there was a re-establishment of flow pattern in outer LOX and fuel rings.

Percent film coolant = 4.7%

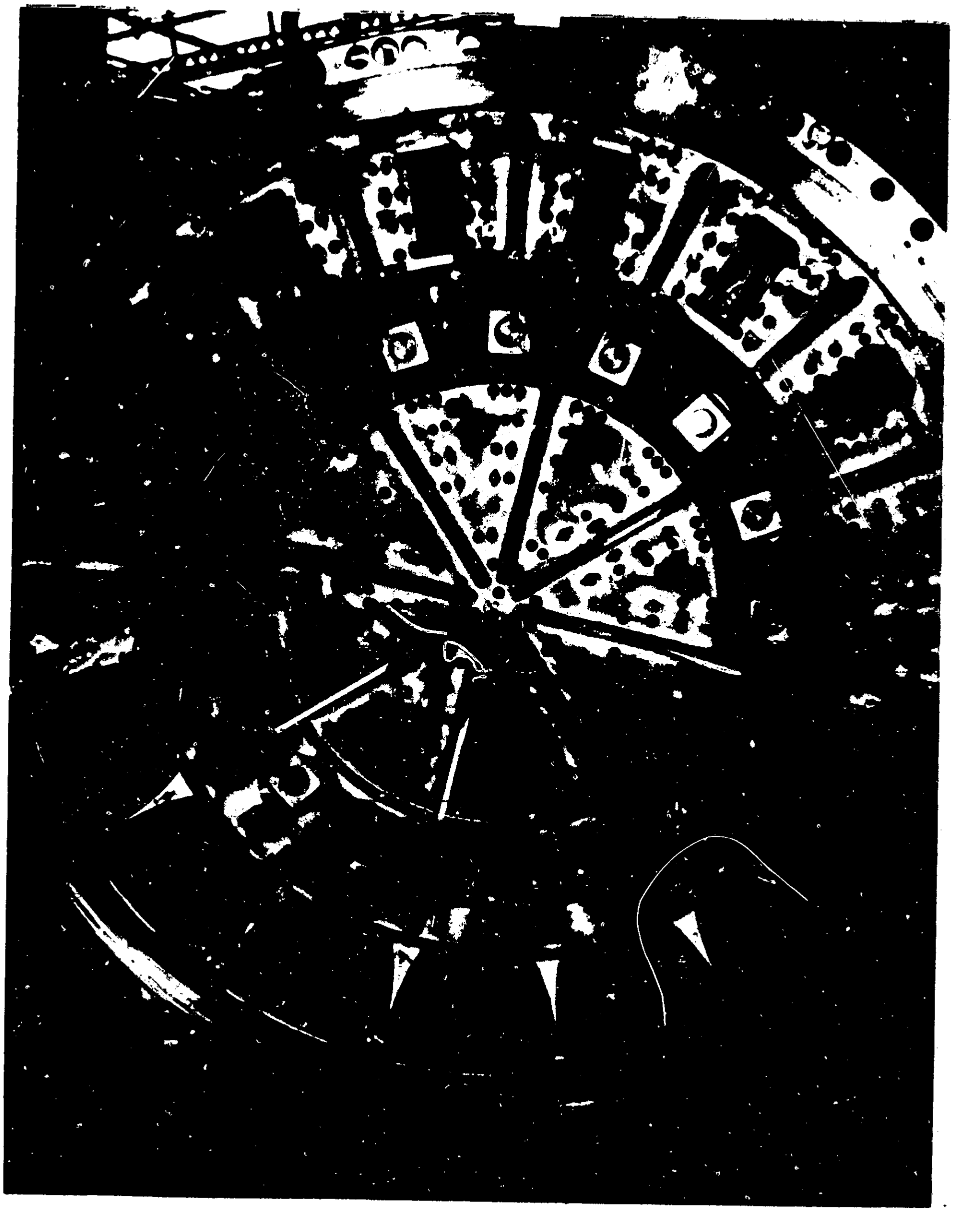
Figure 25. Injector Description, U/N X035, Type 5894 R3



1DB41-1/6/64-C1B

Figure 26. Injector U/N X035, Type 5894-R3, Modified 5U Tri-Baffle Injector (View A)

[redacted]



1DB41-1/6/64-C1A

Figure 27. Injector U/N X035, Type 5894-R3, Modified 5U Tri-Baffle Injector (View B)

[redacted]

[redacted]

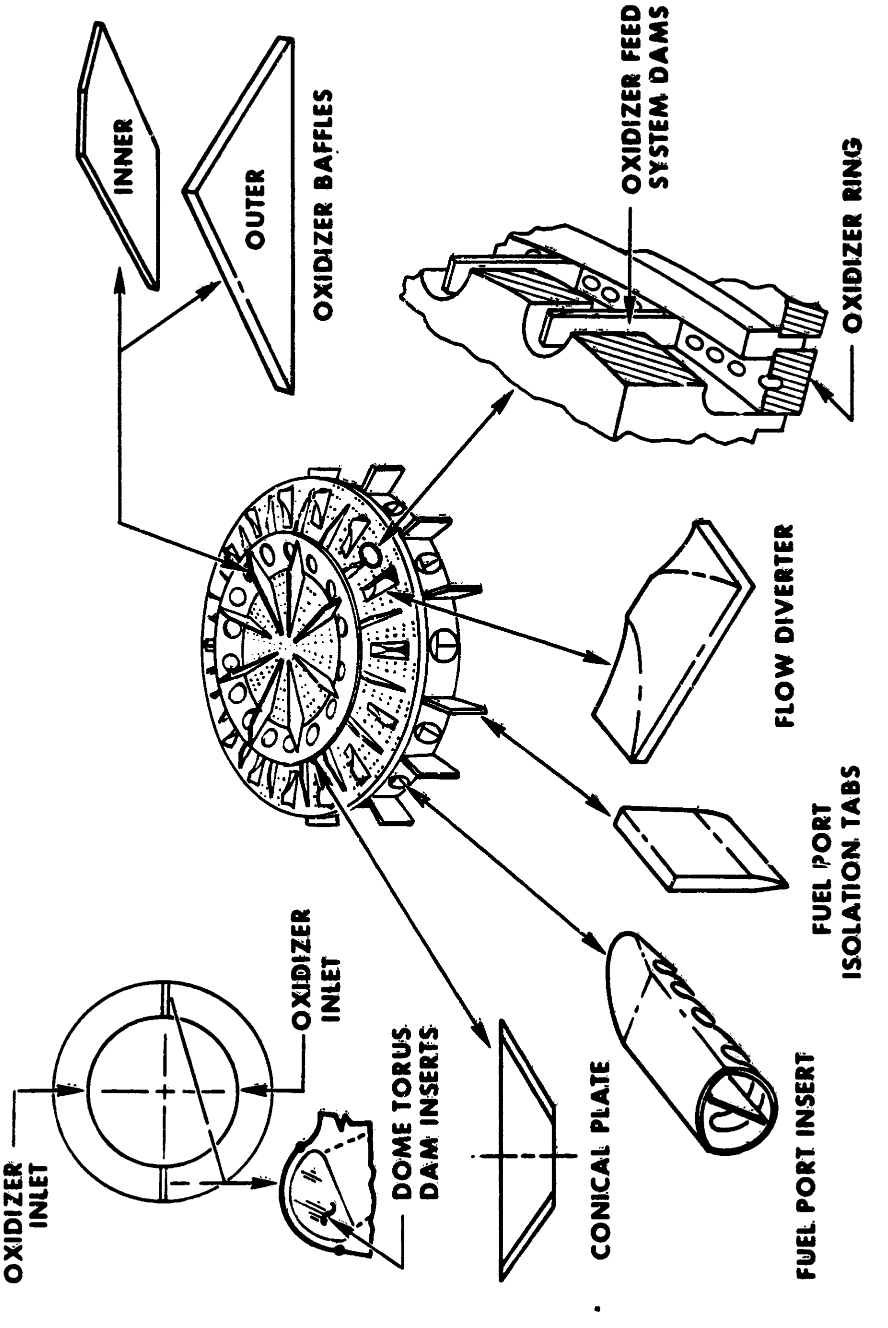


Figure 28. Flow Isolation

[redacted]

[redacted]

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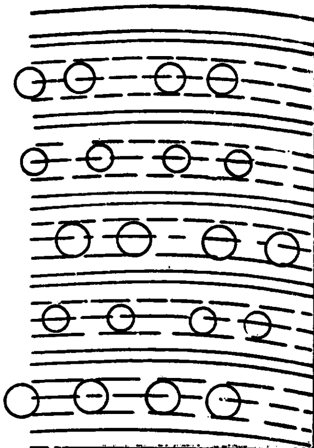
INJECTOR DESCRIPTION

UNIT 082, TYPE 5833 U3, S/N

ORIFICE PATTERN

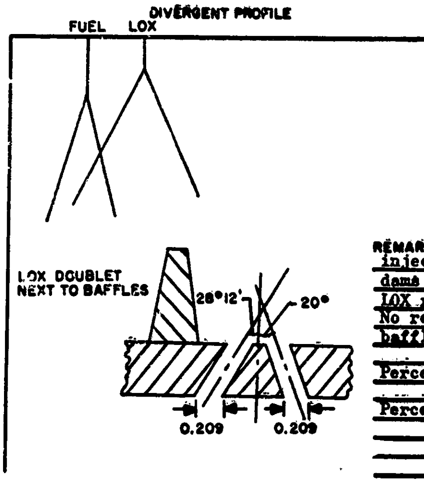


NO.	D	ε	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.374	28.2°	1.11	0.349	0.153
LOX holes next to baffles				0.416	20°		0.571	0.284
-55	35.626	0.281	88/96	0.428	15°	1.17	0.799	0.274
-53	34.506	0.209	88/96	0.374	28.2°	1.13	0.349	0.153
LOX holes next to baffles				0.416	20°		0.571	0.284
-51	33.386	0.281	80/88	0.428	15°	1.19	0.799	0.274

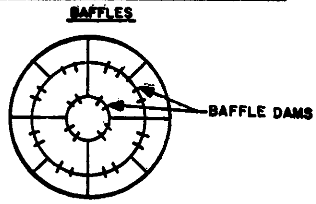
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	49.2
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Velocity (1500K)	55.7	166

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Like U/N 082, Type 5833 D3 except the injector has no splitters. It has 24 baffle dams and 164 fuel ring groove dams. The -9 LOX ring is 0.209-inch-diameter at 20 degrees. No restricted flow in the outer fuel ring. The baffle to land gap is not sealed.

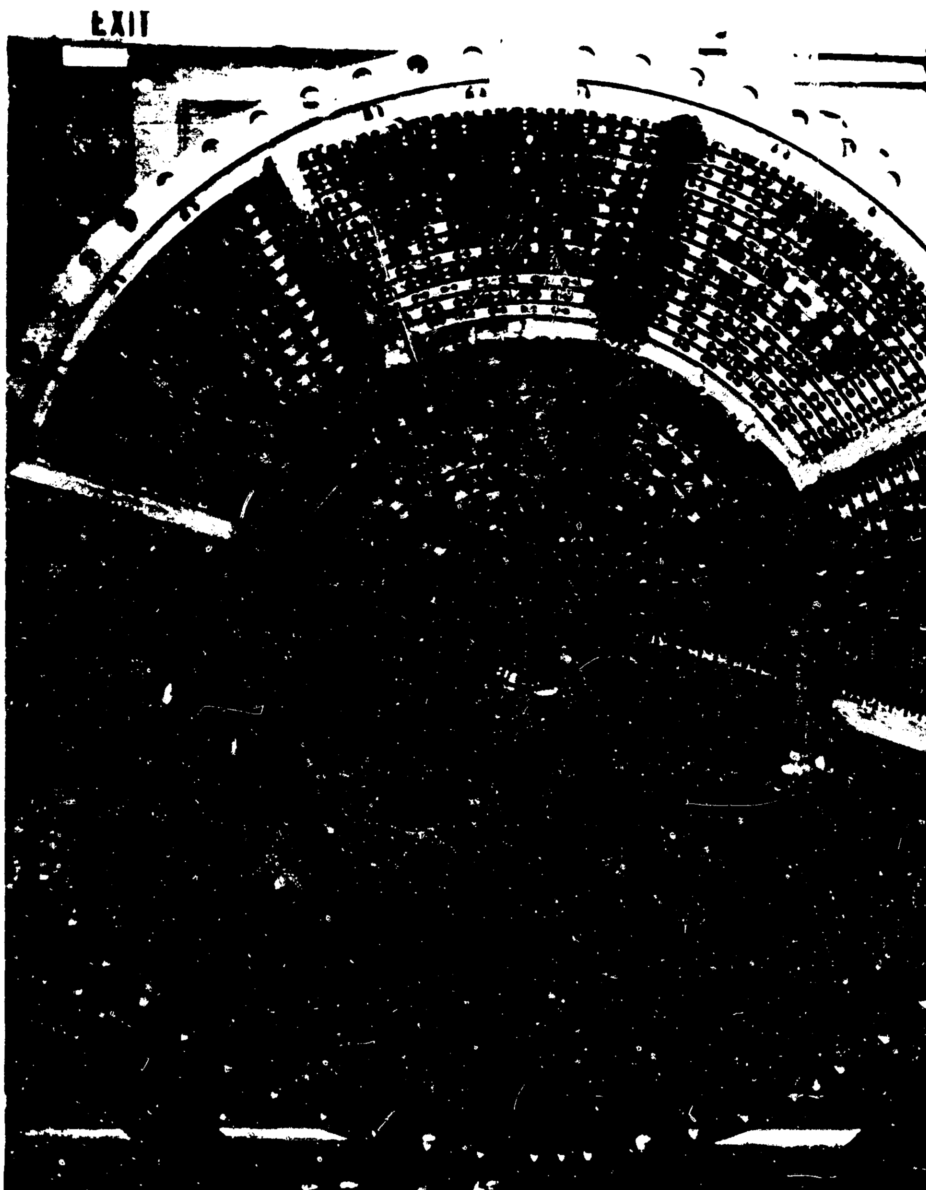
Percent excess fuel on wall = 2.23%

Percent film coolant = 4.6%

Figure 29. Injector Description, U/N 082, Type 5833 U3

[redacted]

[redacted]



1DB41-8/27/64-C1C

Figure 30. Injector U/N 082, Type 5883 U3, Modified 5U Baffled Injector With Large LOX Impingement Angle

[redacted]

[redacted]

Tests were conducted with the original configuration, with the baffle-to-land gap unsealed, and with LOX splitters. In all cases there were indications of 500-cps oscillations in the fuel system.

Injector U/N X002, type 5879 F3 (Fig. 31), is also similar to U/N 082 except that it has large LOX orifices. The LOX orifices are 0.242-inch in diameter except for those adjacent to the baffles and in the outer LOX ring, where they are 0.209 inch. The LOX orifices along the radial baffles are canted as on U/N 082. In one test on this configuration, a 500-cps buzz mode began shortly after 90-percent chamber pressure and continued until cutoff.

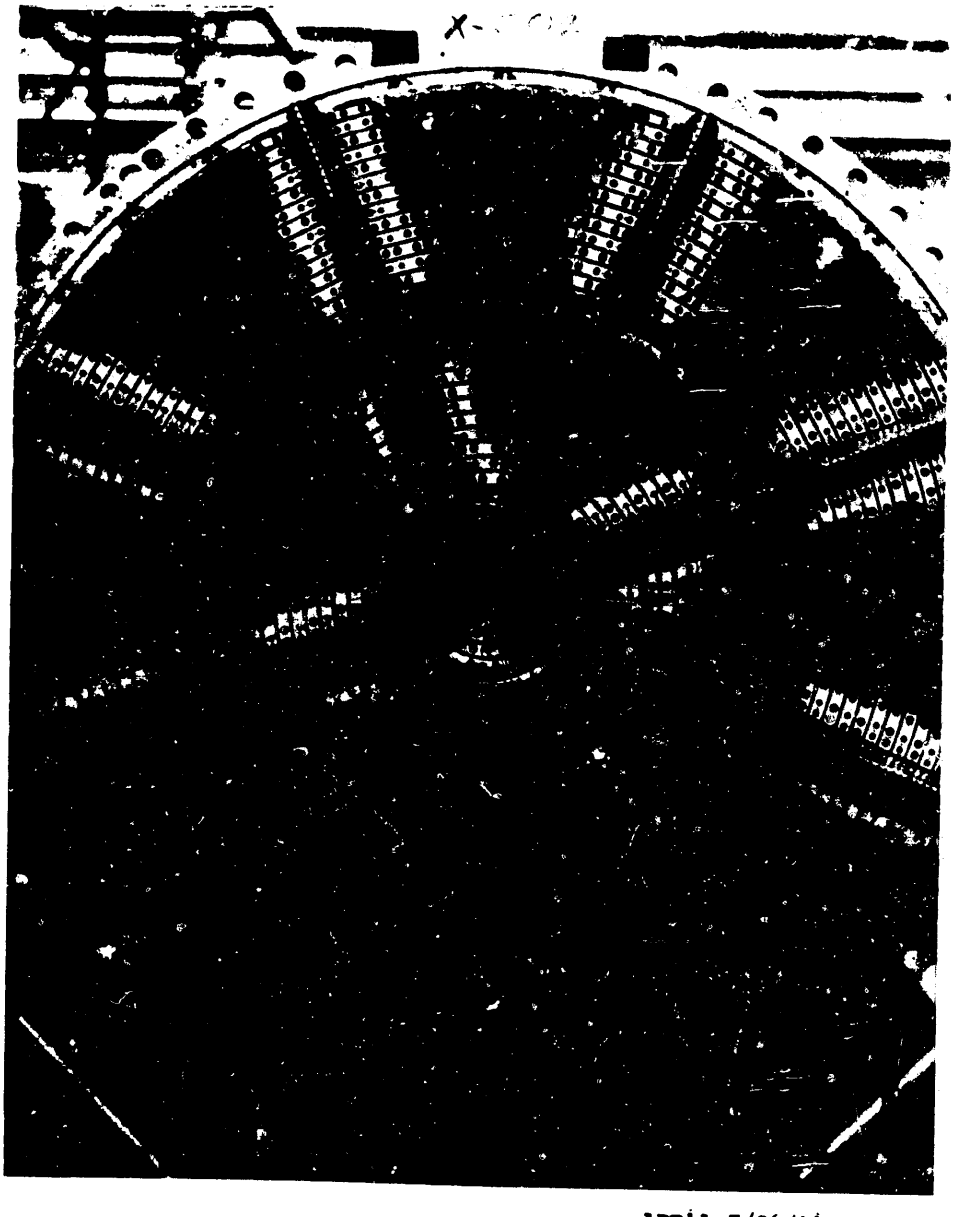
A small, 0.0625-inch-diameter, showerhead orifice (Fig. 32) was added between the LOX doublets to keep the LOX away from the face of the injector. Two unsuccessful tests were conducted with this injector. One test was terminated shortly before the main fuel valve reached the open position; the other was conducted at a LOX-rich mixture ratio. There were no indications of buzzing in the chamber parameters, but 400- and 500-cps oscillations were observed in the fuel parameters. It appeared from the testing that the change in LOX orifice size and the hydraulic modifications employed had little or no effect on the 500-cps buzz, but that the change in fan characteristics produced by the change in impingement angle or type of impingement (i.e., triplets versus doublets) had a primary effect.

WALL GAP

Two tests on two different injectors were conducted to further evaluate the effect of increased wall gap on combustion stability.

It had been found that by plugging the outer two rings on large-fuel-orifice, baffled injectors, dynamic stability could be readily achieved. However, the performance was very low. To improve performance, a small-fuel-orifice injector was built (injector U/N 074, Fig. 33). When tested, combustion

[redacted]



1DB41-5/26/64-C1C

Figure 31. Injector U/N X002, Type 5879 F3, Modified 5U Baffled Injector With Large LOX Orifices

[redacted]

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INJECTOR DESCRIPTION

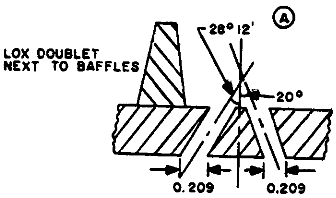
Unit X002 Type 5884 F3 S/N ______

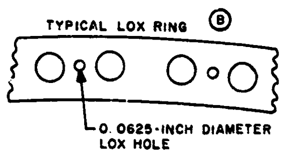
General Information	Fuel	Oxid.
Orifice Area	85.0	61.05
Inj. Velocity (1500K)	55.7	133.8
Ring Groove Depth	0.538	0.538
Ring Material	Cu	Cu
Wall Gap (Fuel Ring)	0.711	
Wall Gap (Outer Zone)	0.966	
Percent Film Coolant	4.6	
Percent Excess Fuel on Wall	2.2	

Baffle Design	
Number of Compartments	13
Baffle Construction	Wide Base
Baffle Coolant	Fuel
Baffle Length	3 inches
Baffle Area	2.31 sq in.

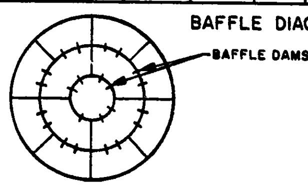
No.	D	d	Groups	Z	θ	Sp	Xjc	Xji
Wall	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	28.2°	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.428	15°	1.17	0.799	0.274
-53	34.506	0.242	88/96	0.416	28.2°	1.13	0.349	0.123
-51	33.386	0.281	80/88	0.428	15°	1.19	0.799	0.274
-49	32.266	0.242	80/88	0.416	28.2°	1.15	0.349	0.123
-47	31.146	0.281	72/80	0.428	15°	1.22	0.799	0.274
-45	30.026	0.242	72/80	0.416	28.2°	1.18	0.349	0.123
-43	28.906	0.281	72/80	0.428	15°	1.14	0.799	0.274
-41	27.786	0.242	72/80	0.416	28.2°	1.09	0.349	0.123
-39	26.666	0.281	64/72	0.428	15°	1.16	0.799	0.274
-37	25.546	0.242	64/72	0.416	28.2°	1.11	0.349	0.123
-35	24.426	0.281	56/64	0.428	15°	1.20	0.799	0.274
-33	23.306	0.209	40/64	0.416	28.2°	1.14	0.349	0.153
OCB	21.066	0.064	256					
-31	18.826	0.209	36/48	0.416	28.2°	1.23	0.349	0.153
-29	17.706	0.281	44/48	0.428	15°	1.16	0.799	0.274
-27	16.586	0.242	44/48	0.416	28.2°	1.09	0.349	0.123
-25	15.466	0.281	36/40	0.428	15°	1.21	0.799	0.274
-23	14.346	0.242	36/40	0.416	28.2°	1.13	0.349	0.123
-21	13.226	0.281	32/36	0.428	15°	1.15	0.799	0.274
-19	12.106	0.242	32/36	0.416	28.2°	1.06	0.349	0.123
-17	10.986	0.281	24/28	0.428	15°	1.23	0.799	0.274
-15	9.866	0.242	24/28	0.416	28.2°	1.11	0.349	0.123
-13	8.746	0.281	20/24	0.428	15°	1.14	0.799	0.274
-11	7.526	0.209	12/24	0.416	28.2°	1.00	0.349	0.153
ICB	6.446	0.089	40					
-9	5.326	0.209	9	0.416	20°	1.88	0.349	0.153
-7	4.206	0.281	9	0.428	15°	1.49	0.799	0.274
-5	3.086	0.242	9	0.416	28.2°	1.10	0.349	0.123
-3	1.966	0.281	5/6	0.428	15°	1.06	0.799	0.274
CD		0.242	3	0.416	28.2°		0.349	0.123

MODIFICATION SKETCHES

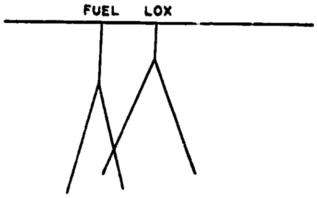




BAFFLE DIAGRAM



INJECTION PROFILE



REMARKS: The injector is the same as U/N X002, Type 5879 F3 except that small (0.0625-inch diameter) LOX showerhead orifices were drilled in each LOX doublet as shown in sketch B at left. The LOX doublets adjacent to the radial baffles are canted away from the baffle. LOX doublets adjacent to all baffles are 0.209-inch diameter at 28.2 degrees; LOX orifices in -9 ring are 0.209-inch diameter at 20 degrees.

Figure 32. Injector Description, U/N X002, Type 5884 F3

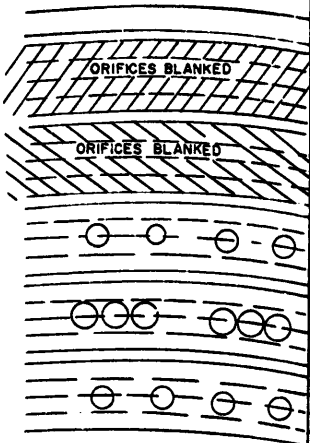
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT 074, TYPE 5872 H3, S/N ______

ORIFICE PATTERN

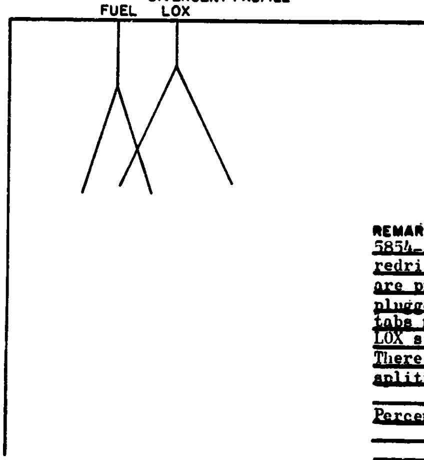


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.766	-----	-----	-----	---	----	-----	-----
-57	36.746	-----	-----	-----	---	----	-----	-----
-55	35.626	0.159	88/96	0.416	20°	1.17	0.572	0.353
-53	34.506	0.221	88/96	0.416	20°	1.13	0.572	0.268
-51	33.386	0.159	80/88	0.416	20°	1.17	0.572	0.353

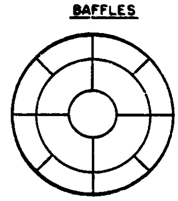
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	26.4	71.46
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
	179.5	114.3

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



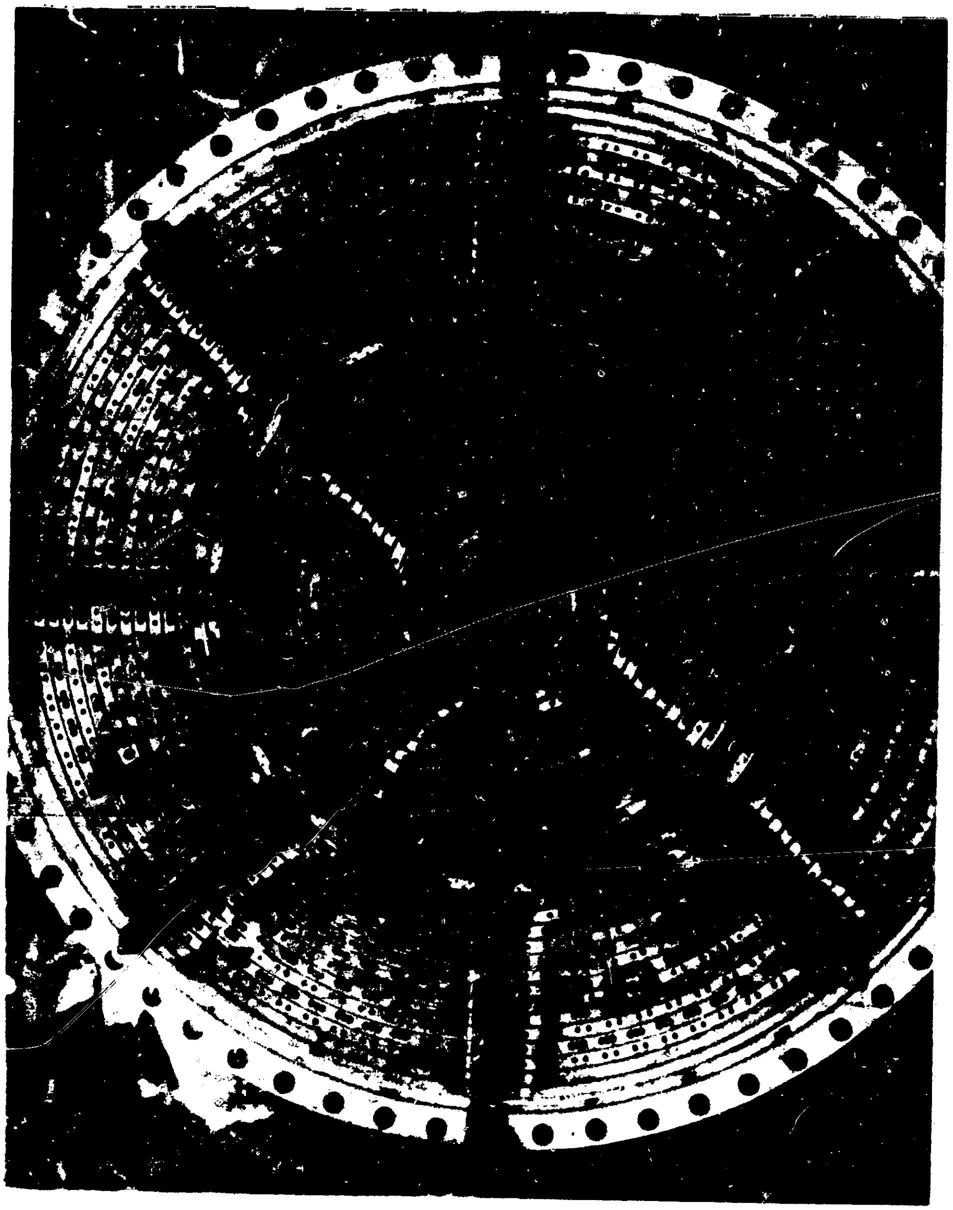
REMARKS: Injector is similar to U/N 074, Type 5854-FF, except the fuel doublets have been redrilled to 0.159-inch diameter. The baffles are programmed and the body coolant holes are plugged. There are neither fuel port isolation tabs nor fuel port inserts. The injector has LOX side baffles and a LOX side divergent plate. There is no film coolant. There are no LOX splitters in the injector.

Percent excess fuel on wall = 6.63% (-)

Figure 33. Injector U/N 074, Type 5872 H3, Modified 5U Baffled Injector With Wall Gap

[redacted]

[redacted]



1DB45-4/29/64-C2D

Figure 33 (Concluded)

[redacted]

[redacted]

instability was bomb-induced and persisted for 750 milliseconds. The mode of instability was essentially the same as that for small-fuel-orifice, 13-compartment, baffled injectors without wall gap. The outer two rings were severly damaged, leaving any conclusions suspect.

Test 273 was conducted on injector U/N X038 (Fig. 34), a flat-face version of the FRT injector with the outer two rings blanked. The bomb-induced instability appeared to be a tangential mode at approximately 700 cps, but many higher frequencies were present. Amplitudes were moderate and much lower than for a normal flat-face instability. However, the injector and dome were both severly eroded, as is commonplace with stability tests on flat-face injectors (Fig. 35). Although increased wall gap improved the stability of the large-fuel-orifice, 13-compartment injector, it was not sufficient to eliminate the tangential mode of a bomb-induced, flat-face instability.

ROTATED FAN INJECTOR

The rotated fan injector, U/N X012 (Fig. 36), is designed such that the spray fans resulting from the impinging streams are rotated to minimize the impingement of unlike fans. The fans are oriented differently in the different areas of the injector. The orifices are small (0.125-inch LOX doublets and 0.0937-inch fuel doublets), and equivalent 1,500,000-pound-thrust injection velocities are 181 and 176 ft/sec for LOX and fuel respectively.

The outer fuel ring consists of fuel showerheads canted 20 degrees toward the chamber wall. The injector has an 11-compartment, 3-inch high, uncooled baffle configuration. The concept which the design of this injector is based upon is that the interaction of the spray fans is caused by transverse pressure waves, and this interaction either reinforces the wave or starts a new wave which causes interactions of other fans.

[redacted]

[redacted]

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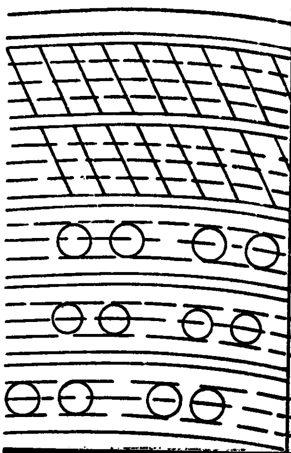
INJECTOR DESCRIPTION

ORIFICE PATTERN

UNIT X038, TYPE 5887, S/N ______

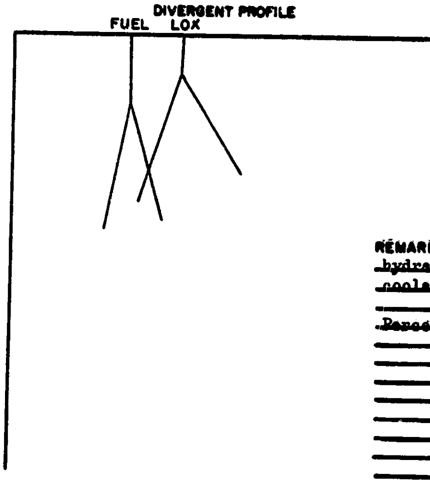


NO.	D	φ	GROUP	Z	θ	Sp	xjc	xji
WALL	39.188							
-59	37.776		Orifices blanked					
-57	36.746		Orifices blanked					
-55	35.626	0.281	94	0.428	15°	1.17	0.799	0.274
-53	34.506	0.242	94	0.416	20°	1.13	0.571	0.238
-51	33.386	0.281	87	0.428	15°	1.19	0.799	0.274

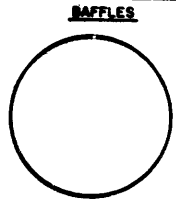
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	93.4	71.2
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
	50.70	114.8

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	None
BAFFLE CONSTRUCTION	——
BAFFLE COOLANT	——
BAFFLE LENGTH	——

DIVERGENT PROFILE



BAFFLES



REMARKS: A 5U flat-face injector with no hydraulic modifications; no film or body coolant.

Percent excess fuel - 6.2%

Figure 34. Injector Description, U/N X038, Type 5887

[redacted]

[redacted]

1DB45-8/25/64-C3F

Figure 35. Posttest Photograph of Injector U/N X038, Type 5887 Modified 5U Flatface With Wall Gap

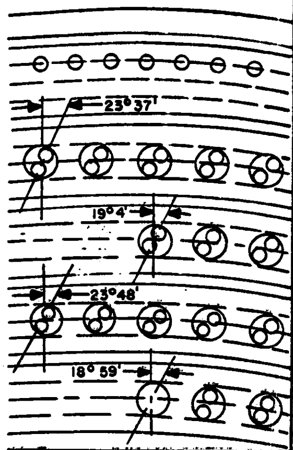
[redacted]

[redacted]

INJECTOR DESCRIPTION

ORIFICE PATTERN

UNIT X012, TYPE 5840 V, S/N

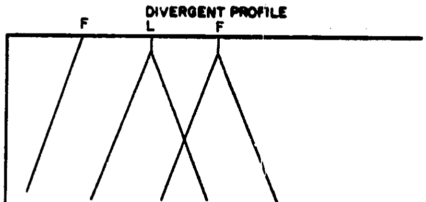


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-69	37.913 37.76	0.125	390	Sh hd	20°	0.292	-----	-----
-67	36.746	0.125	231	0.0732	17°	0.484	0.120	0.085
-65	35.626	0.0937	231	0.0732	17°	0.471	0.120	0.0336
-63	34.506	0.125	217	0.0732	17°	0.484	0.120	0.085
-61	33.386	0.0937	217	0.0732	17°	0.468	0.120	0.0336

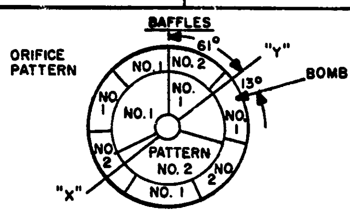
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	28.4	47.30
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.6375	
WALL GAP (OUTER ZONE)	0.9215	
Inj Velocity (1500K)	176	181

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	11
BAFFLE CONSTRUCTION	1/2 inch thick
BAFFLE COOLANT	None
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE

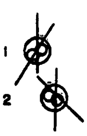


BAFFLES



PATTERN NO. 1

PATTERN NO. 2



REMARKS: 96 body coolant holes, 0.0465-inch diameter; the rotation of the spray fans changes in each compartment according to patterns one and two

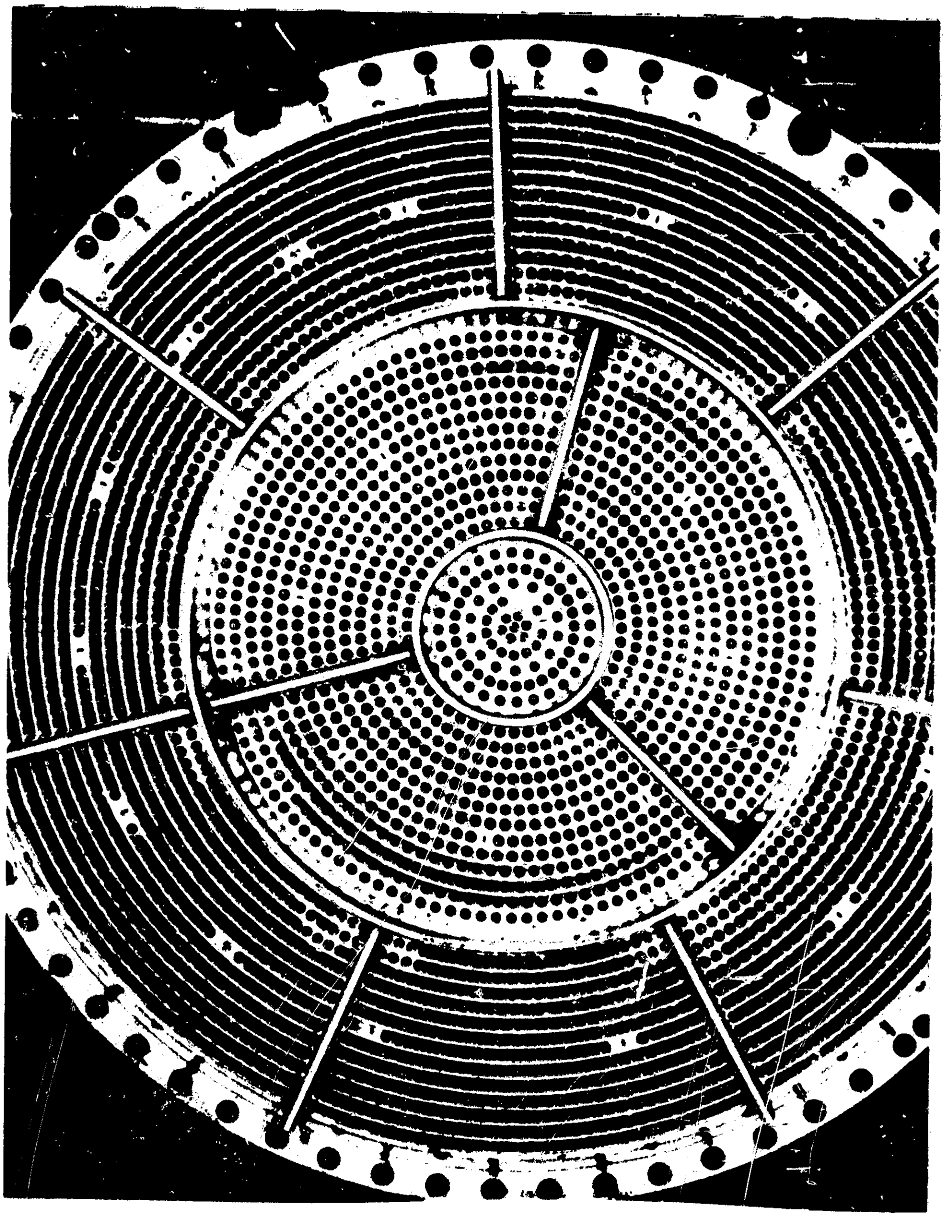
Percent excess fuel in outer ring = 13.5

Percent film coolant = 16.75

Figure 36. Injector U/N X012, Type 5840 V, Rotated Fan Injector

[redacted]

[redacted]



1DB41-1/21/64-C1A

Figure 36 (Concluded)

[redacted]

The first test on this injector resulted in a system self-triggered instability 500 milliseconds after cutoff. The instability ranged from 300 to 500 cps at moderate amplitudes (500 to 700 psi, peak to peak). Phase relationships were not consistent. The outer radials were partially torn loose from the injector face.

The second test conducted on this unit, modified by blanking 168 fuel and LOX orifices next to the outer radial baffles, which were widened to 7/8 inch, was bombed and the instability continued for 700 milliseconds. The oscillations were of high frequency but comparatively low amplitude in all parameters except at chamber pressure taps near the injector face, where amplitudes as high as 5000 psi were recorded. Although the rotated fans were not sufficient to attain dynamic stability, they were effective in eliminating the predominance of the 50 cps mode of instability.

REVERSED 5U PATTERN

Injector U/N X018 has a reversed 5U baffled orifice pattern (Fig. 37). It has 0.157-inch-diameter fuel doublets matched to outboard 0.172-inch-diameter LOX triplets at 40 degrees. The outer fuel ring has 0.128-inch-diameter showerhead orifices canted at 20 degrees toward the wall and 200 body coolant orifices at 0.052-inch-diameter. Wall coolant is 11.6 percent of the total fuel flowrate. The basic concept is to provide oxidizer in the outer periphery and to prevent oxidizer from being displaced into the fuel fans. A checkout test on the injector was successful. In a second test, a 13.5-grain charge induced an instability which caused rough combustion cutoff. The instability was cyclic, in phase, with moderate amplitudes at approximately 250 cps.

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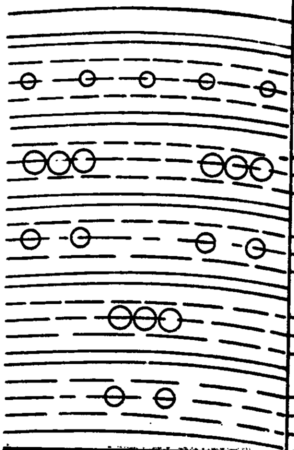
INJECTOR DESCRIPTION

UNIT X018, TYPE 5880 R, S/N ______

ORIFICE PATTERN

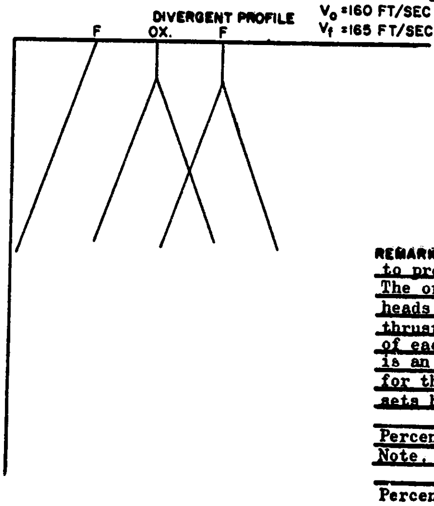


NO.	D	ϕ	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-67	37.766	0.1285	258	Sh hd	20°	0.449	-----	-----
----	37.256							
-65	36.746	0.172	80	0.416	20°	1.15	0.571	0.335
-63	35.626	0.157	80	0.416	20°	1.27	0.571	0.356
-61	34.506	0.172	88	0.416	20°	1.23	0.571	0.335
-59	33.386	0.157	88	0.416	20°	1.19	0.571	0.356

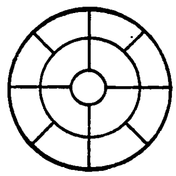
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	28.75	51.0
RING GROOVE DEPTH		
RING MATERIAL		
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Total Orifices	1738	2196

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	half inch
BAFFLE COOLANT	None
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE V_o = 160 FT/SEC V_f = 165 FT/SEC



BAFFLES



REMARKS: Crocco-I design: the basic concept is to provide oxidizer on the outer periphery. The orifices on the outer fuel ring are shower-heads which are directed at 20 degrees to the thrust chamber wall. Note that the outer ring of each set of matched fuel and oxidizer rings is an oxidizer ring which is opposite to that for the 5U in vector. The first three matched sets have the same number of orifice groups.

Percent film coolant = 11.6

Note. 200 body coolant holes of diameter 0.052 inch

Percent excess fuel = 7.77

Figure 37. Injector U/N 018, Type 5880 R, Reversed 5U Orifice Pattern

[redacted]

[redacted]

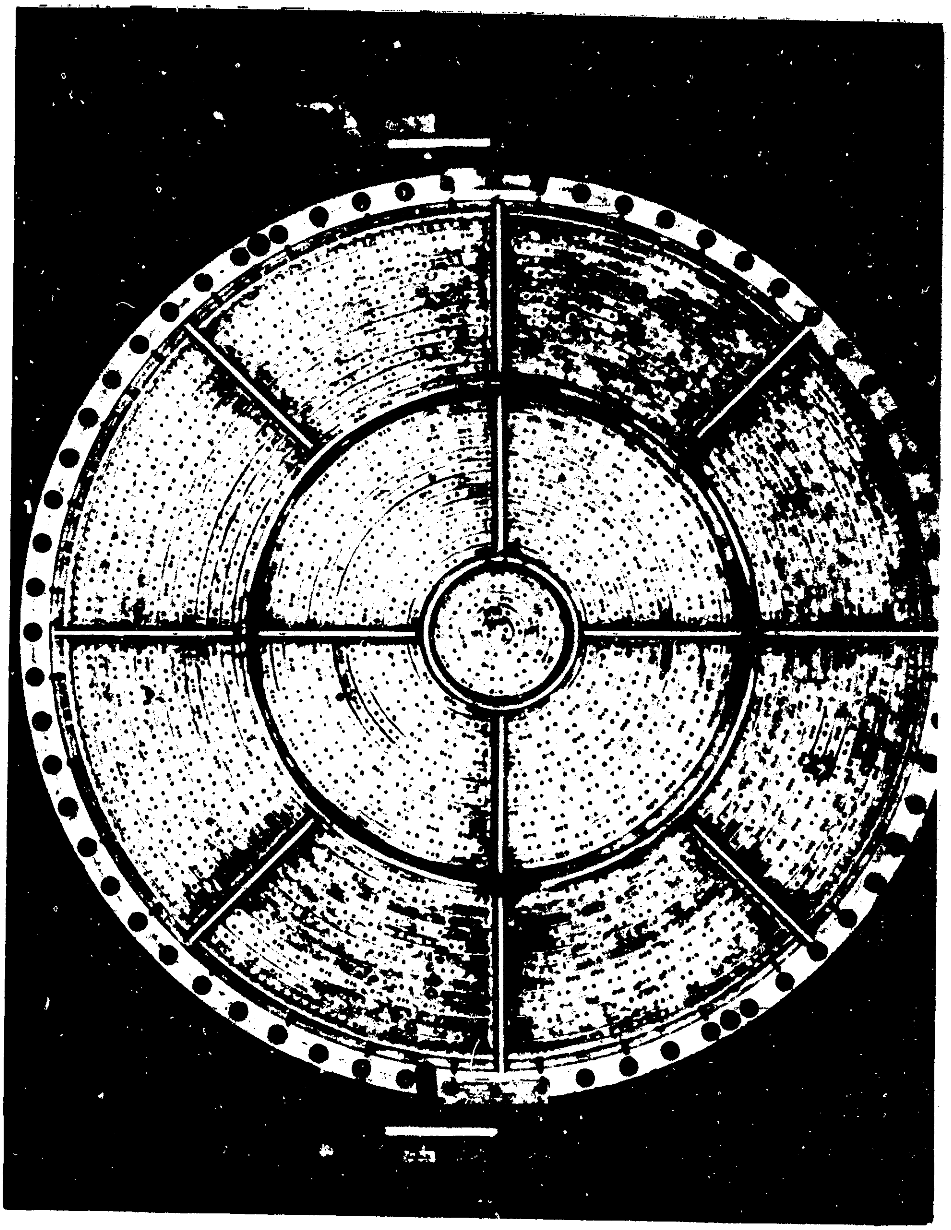


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Figure 37 (Concluded)

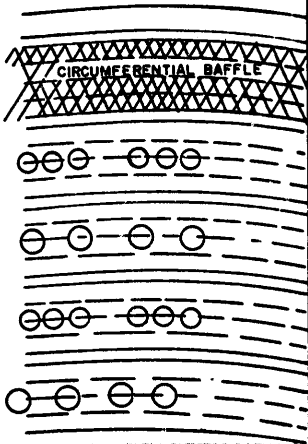
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT X017, TYPE 5870 G3, S/N

ORIFICE PATTERN

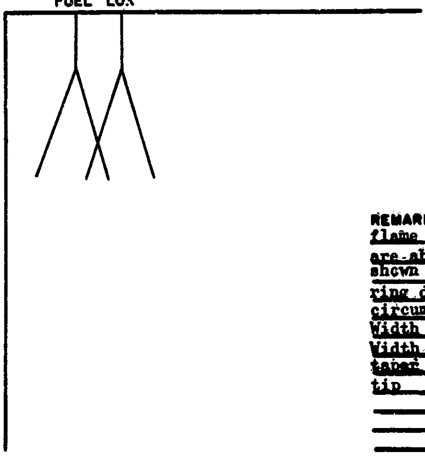


NO.	D	ϕ	GROUP	Z	θ	Sa	Xjc	Xji
WALL	39.188							
-57	36.747	0.166	96/120	0.416	20°	0.963	0.571	0.344
-55	35.627	0.196	96/120	0.416	20°	0.932	0.571	0.302
-53	34.507	0.166	96/120	0.416	20°	1.13	0.571	0.344
-51	33.387	0.196	48/96	0.416	20°	1.11	0.571	0.302

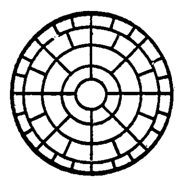
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	30.3	49.3
RING GROOVE DEPTH		
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)		
WALL GAP (OUTER ZONE)		
Inj Velocity(1500K)	156.7	165.8

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	53
BAFFLE CONSTRUCTION	Narrow Base
BAFFLE COOLANT	None
BAFFLE LENGTH	Circumferential = 4 inches
	Radial = 3 inches

DIVERGENT PROFILE



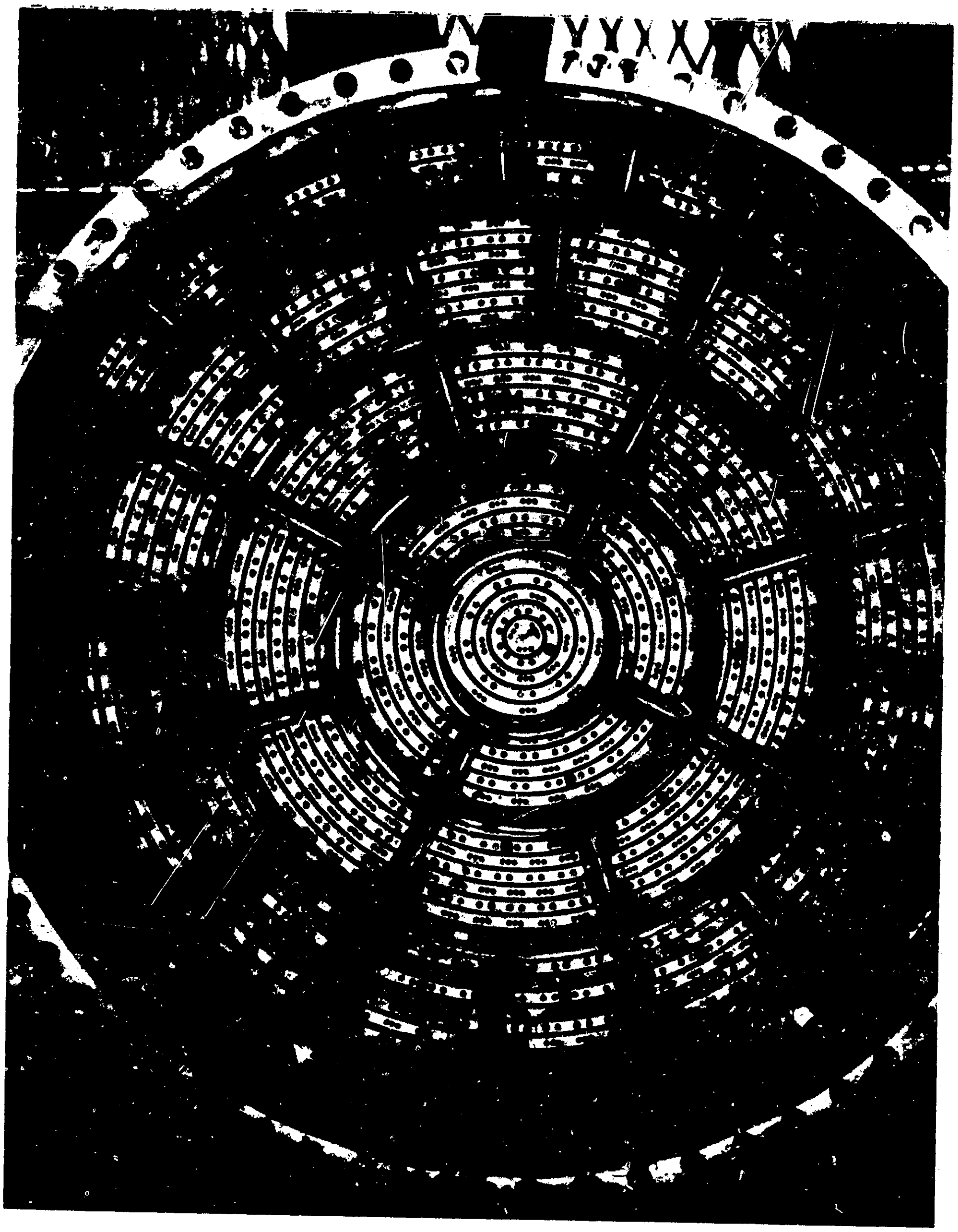
BAFFLES



REMARKS: Injector is Modification 1, and has no flame suppressors and uncooled baffles. There are about 159 fuel ring groove dams placed as shown on the attached sketch. X017 has 215 LOX ring dams. Ring -59 is blanked by the outer circumferential baffle.
Width circumferential baffle = 0.453
Width radial baffle = 0.625 at base start taper at 0.25 inches and tapered to 0.188 at tip

Figure 38. Injector U/N X017, Type 5870 G3, Multicompartment Baffled Injector

[redacted]



1DB41-4/20/64-C1A

Figure 38 (Concluded)

MULTIBAFFLED COMPARTMENT INJECTOR

Injector U/N X017 is a 53-compartment, narrow base, uncooled, baffled injector (Fig. 38). The outer fuel ring is blanked off and covered with a circumferential baffle 4 inches high. One-hundred and four body coolant orifices of 0.054-inch diameter provide all the wall coolant. The fuel doublet orifices are 0.196 inch in diameter and impinge at 40 degrees included angle. The LOX triplet orifices are 0.166 inch diameter and also impinge at 40 degrees. Equivalent 1,500,000-pound-thrust injection velocities are 156.4 and 165.8 ft/sec for fuel and LOX respectively. The injector has hydraulic modification 1 (Ref. Fig. 28), 159 fuel ring dams, and 215 LOX ring dams.

In a 1.1-second test, approximately 1 inch of the solid-wall thrust chamber was nearly uniformly burned away for the entire length of the combustion zone. Several holes burned through the chamber wall so that chamber pressure was decaying prior to cutoff. The bomb detonated during the sequence cutoff and the chamber pressure parameters damped very quickly. However, the accelerometers indicated that the instability did not damp and some very low-amplitude fluctuations persisted in the LOX and fuel measurements. This test reafirmed the concept of keeping oxidizer-rich combustion away from the thrust chamber wall.

COAXIAL STREAM INJECTOR

Evaluation of the F-1 coaxial stream concept was continued. This concept has the fuel and oxidizer injected into the chamber through concentric elements (Fig. 39 and 40). Mixing is accomplished by swirlers in the inner tube which force LOX into the fuel being injected from the outer tube. The concentric elements are of varying length, some being flush with the injector face and some 3 inches high. The variable-length

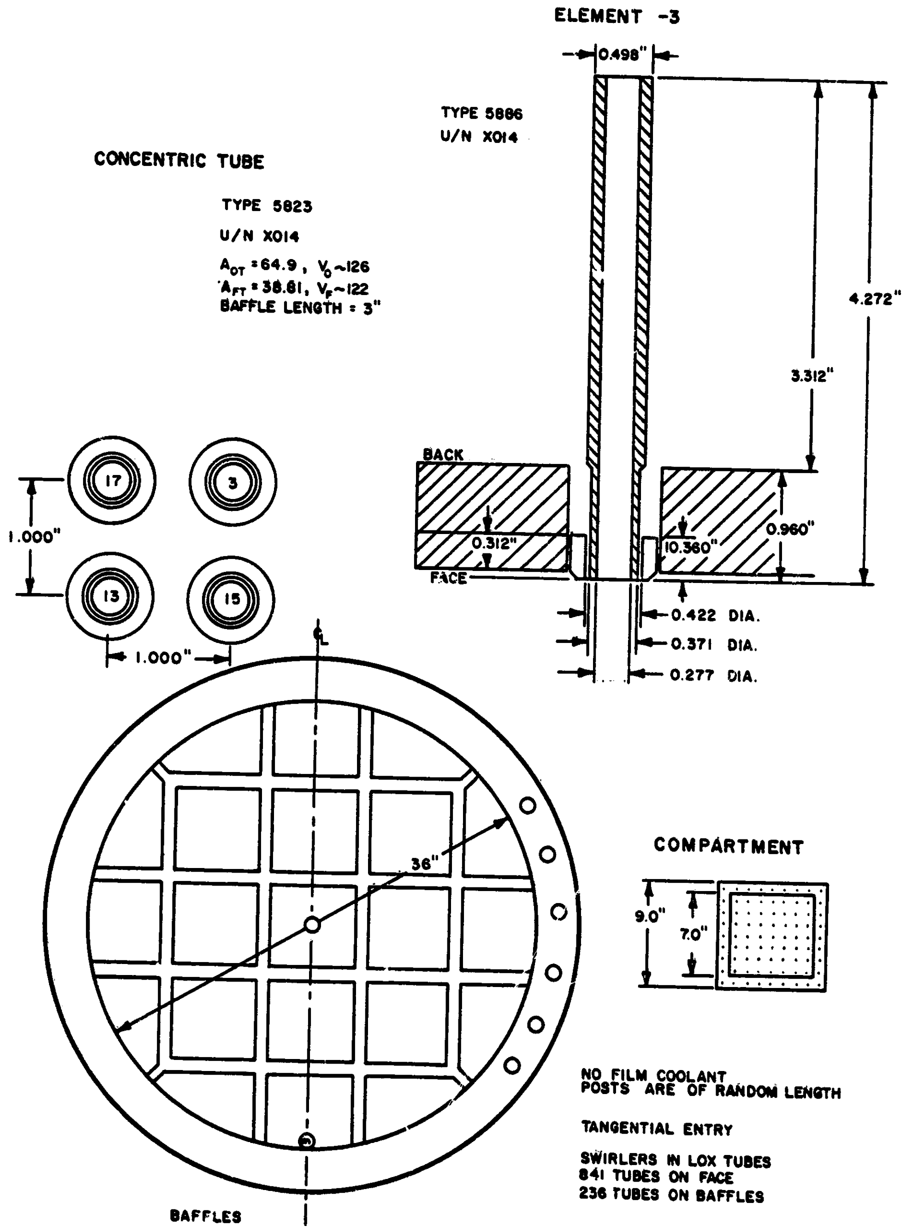


Figure 39. Injector U/N X014, Type 5886, Coaxial Stream Injector

OXIDIZER AND FUEL RING DAMS SKETCH

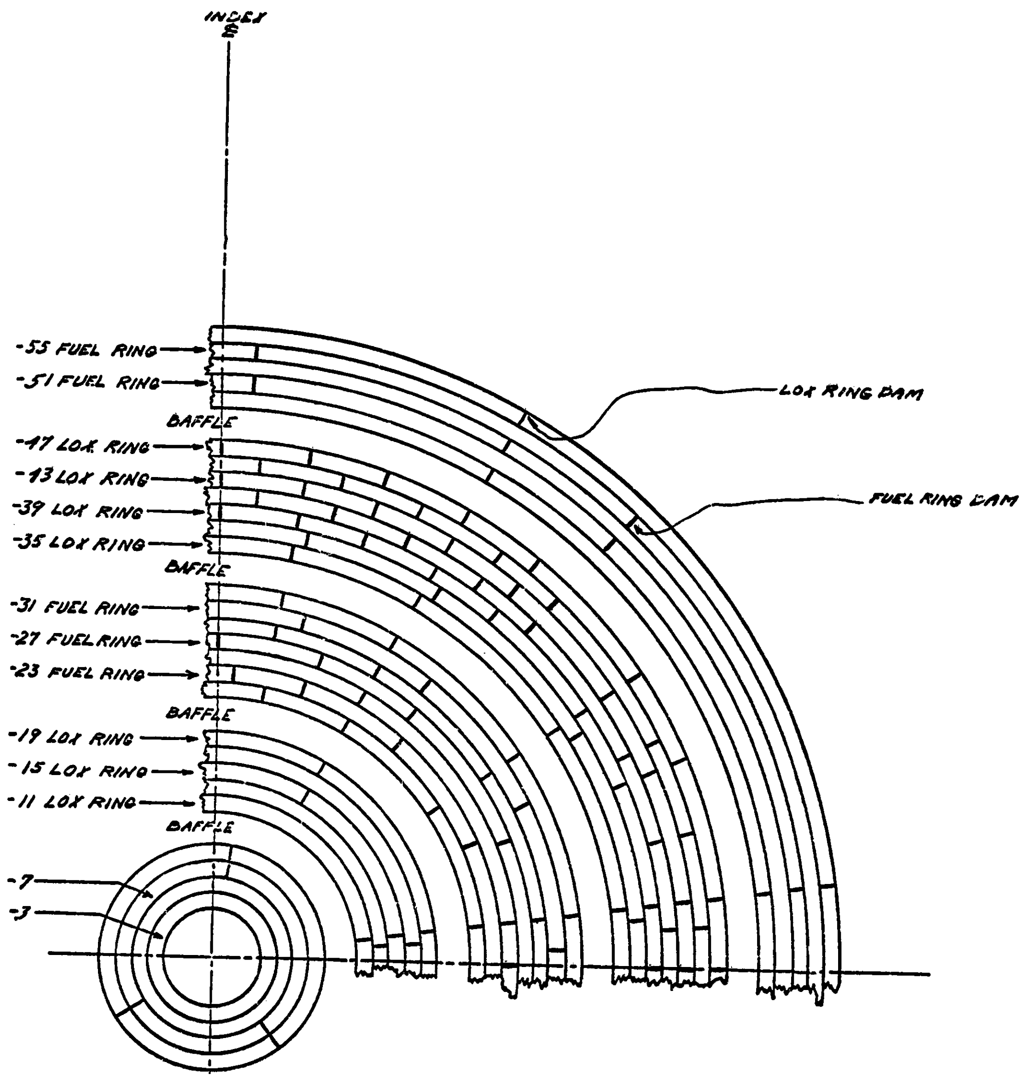


Figure 39 (Concluded)

[redacted]

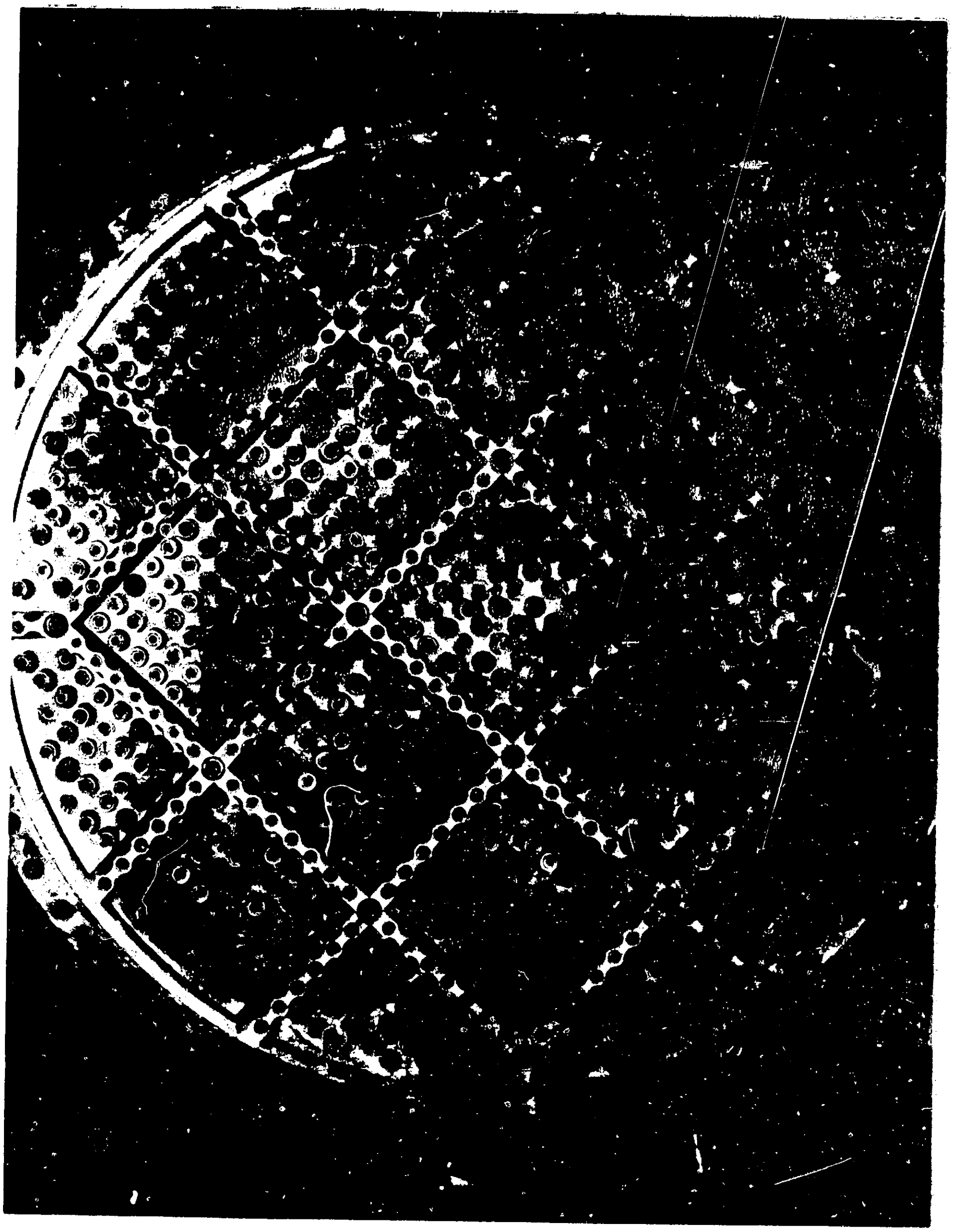


Figure 40. Injector U/N X013 (Posttest photograph not available on X014. Injector X013 is identical to U/N X014 except that U/N X014 has tangential entry to LOX tubes, whereas X013 has six-vane entry)

[redacted]

posts are scattered randomly across the injector. The injector has a 21-square-compartment, 3-inch high, baffle configuration. The baffles are cooled by coaxial elements.

Three checkout tests were conducted on a coaxial stream injector U/N X014. In the first test, the system self-triggered instability and a rough combustion cutoff was incurred. The mixture ratio was high at 2.87. The second and third tests were conducted at near-nominal conditions and 11 and 9 separate self-triggered instabilities occurred during the tests. Both tests were terminated by the rough combustion cutoff device. Damp times of the individual self-triggered instabilities varied from 5 to 198 milliseconds. Triangulation showed a random distribution in the location of the self-triggered instabilities. The mode of instability when "set up" was a 500-cps transverse mode, with moderate chamber and feed system amplitudes.

[redacted]

DESIGN

The design effort during this report period was directed toward the modification and rework of existing injectors for continued evaluation of combustion stability and performance. These modifications have been discussed in the test analysis section of this report. Additional effort was made in the design of: an FRT injector with steel-reinforced radial baffles, a variable-injection-density, flat-face injector, and injectors incorporating a copper ring at the outside diameter of the injector face. Also, the coaxial stream injector, U/N X014, was repressure checked to verify the integrity of the interpropellant braze joints.

REINFORCED RADIAL BAFFLES

The radial baffles on injector U/N X054 were reinforced by using stainless steel posts inserted into the modified copper baffles and attached to a stainless steel base. The baffles were assembled and brazed as a unit with the injector. This design minimizes the baffle bending incurred from stability rating tests of F-1 injectors. The calculated comparative resistance to bending of the new baffle compared to the existing design showed an improvement of 4 to 6 times, except at the baffle tip where only slight improvement was realized. A new brazing alloy was used locally under the baffles to check its ability to seal the baffle-to-ring land gaps and to eliminate the necessity of post-braze tungsten inert gas welding then being used to seal these gaps. Water flow tests were conducted to ensure similar fuel coolant flowrates between the old and redesigned baffles.

[redacted]

VARIABLE-INJECTION-DENSITY INJECTOR

Unit No. 077 was designed as a flat-face injector. The injection density (total pounds of propellant per sq in. of injector face area) is programmed in the outer six rings from 5.24 lb/sec sq in. to 3.00 lb/sec sq in. adjacent to the thrust chamber wall. Both fuel and oxidizer orificing was controlled by varying hole sizes from ring to ring to produce uniform mixture ratio and the desired injection density across the injector face. The radial fuel feed passages were modified by multiple step drilling to reduce the effects of large area contraction ratios on flowrate to the individual rings.

OUTSIDE DIAMETER COPPER RING

Flight rating test injectors U/N X051 and X052 were modified to incorporate a copper ring on the outer periphery of the injector just below the lower O-ring seal. This design provides improved heat transfer in this area and minimizes burning and the excessive thermal stress which caused ring-to-land cracks at the ends of the radial baffles.

COAXIAL STREAM INJECTOR

Coaxial stream injector U/N X014 was returned to the Canoga Park facility after a test series in which 21 self-triggered combustion instabilities occurred. The injector was repressure checked to verify the integrity of the 1077 interpropellant braze joints. The 500-psi pressure check revealed no leakage. The only apparent damage to the injector was 13 fuel posts burned and one loose copper tip at the exit of the oxidizer tube. The burned tubes were randomly located in the outer baffle compartments. The loose copper tip appeared to have resulted from an interpropellant leak at the end of the injection element. The resulting detonation expanded the copper tip outward, and closed the annular fuel orifice. Repeated leakage and detonation may have contributed to the 21 self-triggered instabilities.

SPUD INJECTOR

The single spud testing program at the Neosho Facility was designed to furnish information for spud evaluation prior to testing of the F-1 spud injector. The first spud type chosen for testing was the radial flow spud. The radial flow spud extends past the injector face into the combustion zone, and propellants are injected radially from the spud. The following record of tests (Table 2) shows that spud erosion occurs on most orifice configurations of the radial flow spud. Erosion was eliminated on many of these spuds by the addition of fuel coolant holes, but not without a performance loss.

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TABLE 2

SPUD-TYPE INJECTOR TESTING SUMMARY

Tests:	51
Spud Type:	Radial flow spud element (-11B)
Description:	32 radial elements; each element consists of one 30-degree LOX doublet and two 30-degree fuel doublets; axial pattern of four 60-degree LOX doublets and 16 30-degree fuel doublets; fuel coolant holes after each radial LOX doublet
Objective:	Evaluation of performance data and spud erosion
Test Results:	No spud erosion; specific impulse = 206 mixture ratio = 2.329
Tests:	53, 56, and 57
Spud Type:	Radial flow spud element (-21)
Description:	Radial elements and fuel coolant same as spud -11B axial pattern; plugged two LOX doublets
Objective:	Increase specific impulse and prevent spud erosion
Results:	No spud erosion Test 53: Specific Impulse = 209 Mixture Ratio = 2.270 Test 56: Specific Impulse = 193 Mixture Ratio = 2.292 Test 57: Specific Impulse = 213 Mixture Ratio = 2.324
Tests:	59 and 60
Spud Type:	Radial flow spud element (-22)
Description:	Radial elements and fuel coolant same as spud -11B, axial pattern; all LOX holes plugged and eight fuel doublets plugged
Objective:	Increase specific impulse and prevent spud erosion
Results:	No spud erosion element (-23) Test 59: Specific Impulse = 210 Mixture Ratio = 2.330 Test 60: Specific Impulse = 204 Mixture Ratio = 2.230
Tests:	61 and 63
Spud Type:	Radial flow spud element (-23)
Description:	Radial elements same as spuds -11B, -21, -22; all fuel coolant plugged except two holes after each LOX doublet; no axial pattern

[redacted]

TABLE 2

(Continued)

Results:	Very slight spud erosion on both tests Test 61: Specific Impulse = 203 Mixture Ratio = 2.280 Test 63: Specific Impulse = 230 Mixture Ratio = 2.240 Increased chill-down time for run 63
Tests:	62
Spud Type:	Radial flow spud element (-24)
Description:	Radial pattern same as spud -11, -11A; two fuel coolant holes after each LOX doublet; axial pattern of eight 30-degree fuel doublets
Objective:	Evaluation of performance data and hardware
Results:	No spud erosion; Specific Impulse = 213 Mixture Ratio = 2.240
Tests:	66, 67, 68, 70, 71, 73, 74, 75, 76, 77, 78, and 80
Spud Type:	Radial flow spud element (-25)
Description:	32 radial flow spud elements, none axially; each element consists of two fuel doublets and one LOX doublet which impinge at a common point
Objective:	Compile performance data and evaluate hardware
Results:	Instrumentation difficulties were experienced during most of these tests; specific impulse varied from 228 to 240 at mixture rato = 2.343 and 2.378; fuel coolant holes were added during these tests but failed to completely eliminate spud erosion
Tests:	69
Spud Type:	Radial flow spud element (-26)
Description:	48 radial elements; each element has one oxidizer doublet and four fuel doublets; none axially; fuel impinges in and below oxidizer impingement point
Objective:	Evaluation of performance data and hardware
Results:	Spud eroded; Specific Impulse = 225 Mixture Ratio = 2.697
Tests:	64 and 65
Spud Type:	Radial flow spud element (-27)
Description:	Same as spud -23 except fuel coolant holes relocated
Objective:	Increase specific impulse and prevent spud erosion
Results:	Very slight spud erosion on both tests Test 64: Specific Impulse = 213 Mixture Ratio = 2.410 Test 65: Specific Impulse = 219 Mixture Ratio = 2.450

[redacted]

TABLE 2

(Concluded)

Tests:	85
Spud Type:	Radial flow spud element (-28)
Description:	Four planes of oxidizer and fuel doublets with impinging fans
Results:	Spud erosion; Specific Impulse = 219 Mixture Ratio = 2.080
Tests:	82 and 84
Spud Type:	Radial flow spud element (-29)
Description:	Four planes of oxidizer and fuel doublets with impinging fans and orifice holes sized to allow the most flow through the first plane and lessening flow through the remaining planes
Objective:	Prevent spud erosion
Results:	Slight spud erosion on both tests Test 82: Specific Impulse = 239 Mixture Ratio = 2.327 Test 84: Specific Impulse = 241 Mixture Ratio = 2.300

FRT-type injector has smaller oridizer orifices on those rings which are bounded by baffle surfaces. Flow deviation percentages on such rings were always less than on other rings.

Flow tests were conducted at the Medium Flow Facility to determine the best combination of orifice size and angle to use for LOX groups adjacent to the radial baffles. The configuration offering the best canted oxidizer fan consisted of a 0.250-inch diameter orifice drilled at 28 degrees 12 minutes relative to the chamber axis and mated with a 0.242-inch diameter orifice at 20 degrees.

Flow tests were also conducted on models of various radial feed port configurations (Fig. 41 through 43). Included among these were the standard, step-drilled-type port, a modification thereof having a 40-degree included step angle, and a constant angle tapered port design. Of these three configurations, the tapered port design gave distribution results closest to the desired theoretical flow.

[redacted]

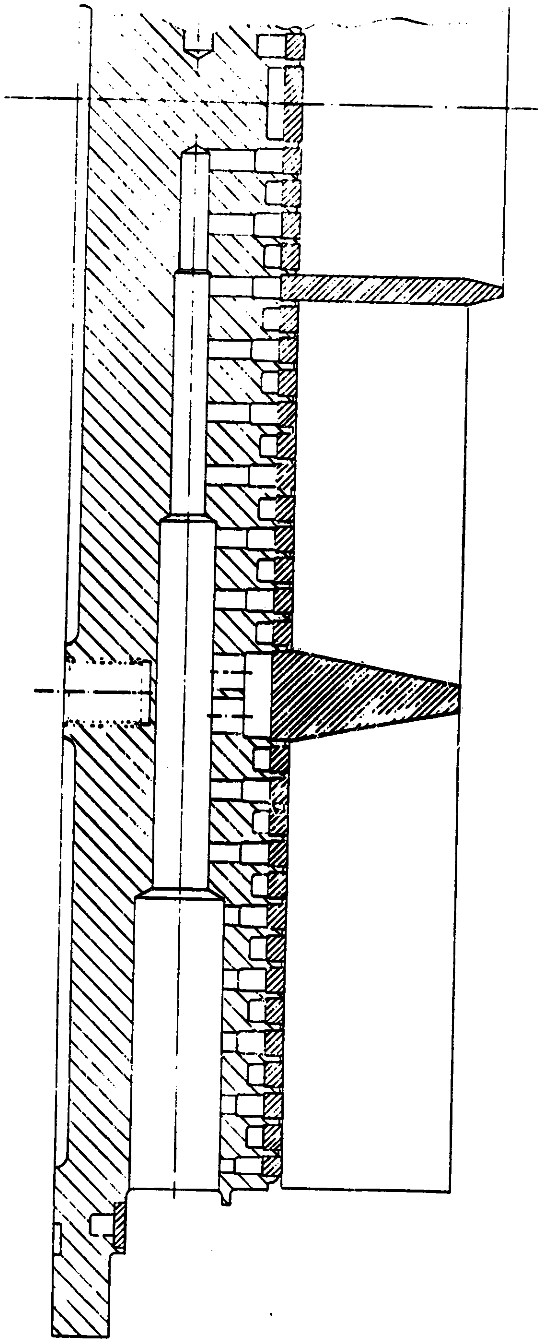

Figure 41. Existing Fuel Radial Design

[redacted]

[redacted]

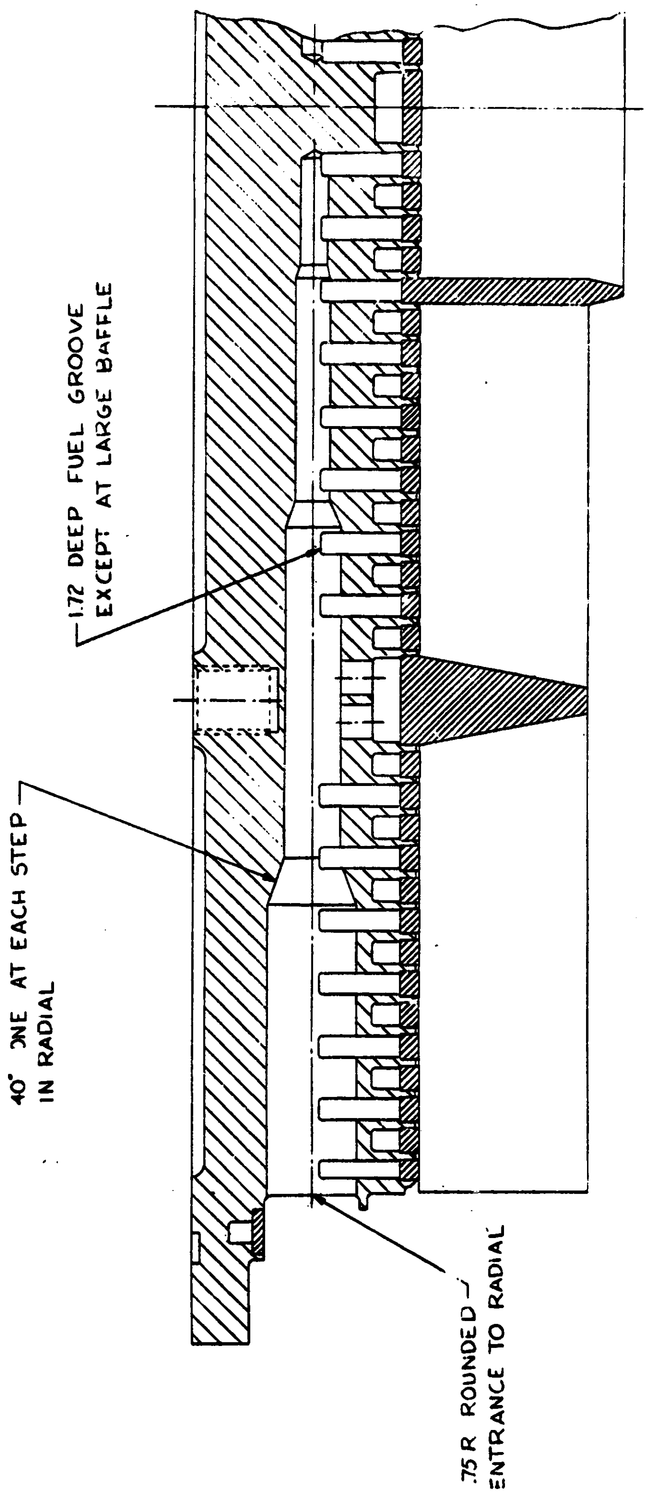

Figure 42. Proposed Modifications to the Existing Fuel Radial Design

[redacted]

[redacted]

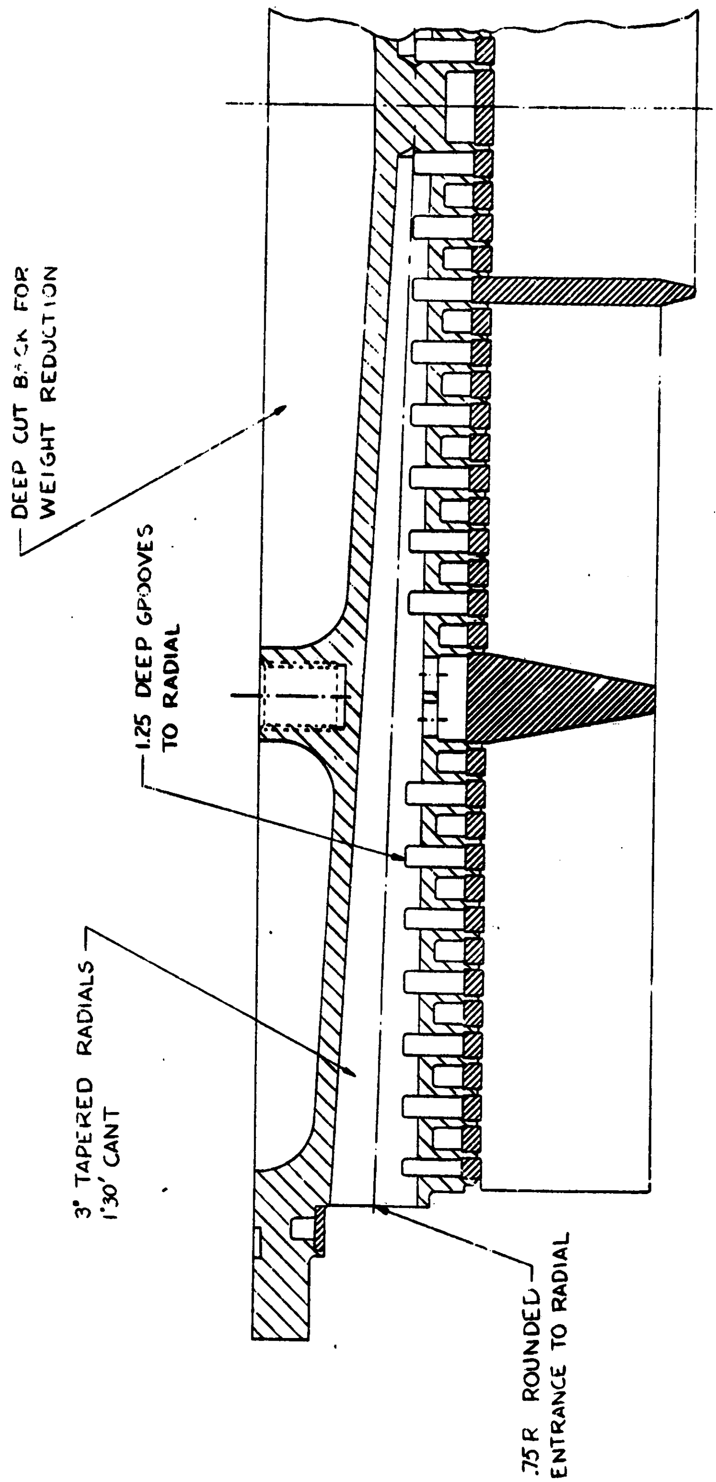

Figure 43. New Fuel Radial Design

[redacted]

[redacted]

HYDRODYNAMICS

The first phase of planned testing on the oxidizer side of F-1 injectors was completed. This testing included flowing most of the primary FRT candidate injectors and flowing the full-scale coaxial stream injector. Unit No. X050, a baffled injector with a standard body, was used for the FRT type testing. Modifications to the ring set and the injector body (mostly involving changes in LOX axial feed hole splitter configurations) were made to convert the injector from one type to another. Testing also involved the use of both the prototype and production low-differential-pressure domes. The coaxial stream injector testing was on U/N X013.

Analysis of the reduced data from these tests has shown several pertinent facts concerning oxidizer distribution. Group by group, the distribution across the face of F-1 injectors is fairly uniform. Individual group flow on any given ring was found to deviate from the mean group flow by approximately 10 percent on the high side and by approximately 8 percent on the low side. These are average percentages for the entire injector. Total ring flowrates and flow densities, with a few exceptions, were very close to predictions based on design.

It was found that kinetic head and the placement of splitters in axial feed passages play an important role in whether a particular orifice flows higher or lower than the mean. These results were also obtained by the flow distribution model and have been discussed under that section.

It was also discovered that smaller orifice sizes tend to retain more of the flow control through an injector ring at the orifices themselves. The

[redacted]

RESEARCH

TWO-DIMENSIONAL TESTING

Investigations continued in order to explain repeated pressure surging. It was theorized that LOX and fuel might be accumulating and detonating. Two small 1/2-inch baffles were added at the ends of the injector to provide a pocket area next to the chamber wall where fuel and LOX could conceivably mix without combustion occurring. However, no repeated pressure surging was observed on tests of this configuration.

An injector was designed to generate combustion gases near the injector face. It was thought that small unlike doublets would provide a high relative gas velocity with respect to the large showerhead propellant orifice to provide good secondary atomization. This should have resulted in a highly efficient injector. When tested, the flat-face injector was spontaneously unstable in the first transverse mode and the test was terminated by the rough combustion cutoff device. The efficiency, as measured by the characteristic velocity (c*), was poor. The low c* (4624 ft/sec) was probably caused by poor mixing of the secondary atomized propellant sprays (sprays from showerhead orifices) and by leakage around the injector.

The 500-cps, buzz-type instability which occurred on the F-1 injector U/N X040 was investigated. An X040 type orifice injector pattern with four 3-inch baffles was used. The chamber width in the injection region was decreased by laminating an extra thickness of pyrex, extending for the first 3-1/2-inches downstream of the injector face, on both of the combustor walls. It was thought that the decreased injection density

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would enable the two-dimensional motor to model the buzz observed on the F-1. Buzz-type instabilities were observed. The frequency of the oscillations was 650 cps, as determined by a hand count from reduced speed oscillograms. The amplitude peak from a sonic analysis indicated the frequency to be 900 cps.

A high-pressure, two-dimensional injector with three separate manifolds for both oxidizer and fuel was fabricated. This allowed independent variation of mixture ratio and injection density of both propellants in the upper, middle, and lower sections of the injector. This hardware allowed the evaluation of asymmetries in these two quantities (which may exist in the full-scale F-1 engine owing to feed system distribution of propellants).

One test with a small fuel hole, 5U injection pattern with two 3-inch baffles (used to separate the combustion chamber in the same relation as the manifolds) has been made. In this test the injection density was constant in all three regions, but the mixture ratio was 1.8, 2.4, and 3.5 from top to bottom. A 13.5-grain bomb detonation in the upper compartment resulted in an instability (third transverse mode: typical of this injector type with uniform mixture ratio distribution) which did not recover. The injector showed a c* of 5400 ft/sec, which is about 300 ft/sec higher than the average for this type injector.

Streak photographs of two-dimensional tests were analyzed. They indicated that only small differences occur among RP-1/LOX combustion gas velocities, regardless of the injector used.

Unsymmetrical dimethyl hydrazine/LOX and ethanol/LOX propellant combinations gave gas velocities which appeared to be a function of orifice size and the angle of impingement. They gave consistently higher combustion gas velocities in the first 10 to 15 inches of the chamber length than the RP-1/LOX combinations.

A model of the F-1 gas generator acoustic liner was tested to evaluate its absorbtive characteristics (For Theory see Volume 2, Book 3). The results (Fig. 44) show that the resonance peak at 1980 cps, which existed for the solid-liner case, was attenuated approximately 25 decibels when the acoustic liner was introduced. This represents a decrease in oscillatory energy to 1/16 the original value. A new resonance peak was established at 2200 cps. However, the amplitude was approximately 15 decibels below the peak value established by the solid-wall configuration.

[redacted]

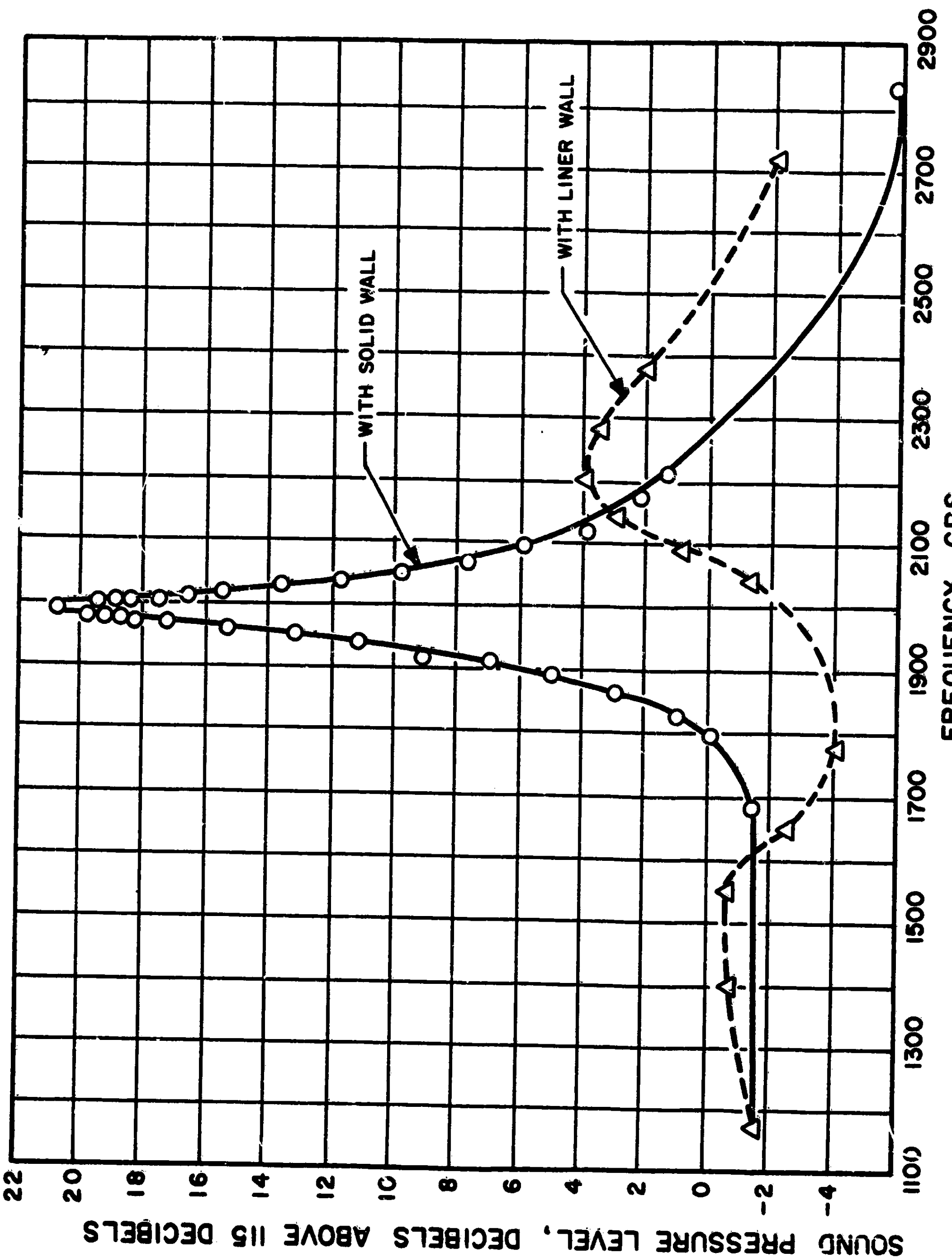

Figure 44. Acoustic Liner Testing

[redacted]